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Improving productivity in pipe renovation project by standardized solutions

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Tiivistelmä

Rakennusalan tuotanto koostuu kompleksista prosesseista, jotka toteutetaan dynaamisessa ympäristössä. Tämänkaltaisen tuotannon prosessit sisältävät paljon vaihtelua, mikä hankaloittaa tuotannon tehokkuutta sekä hallintaa. Tämän lisäksi rakennusalalla työmaiden menettely- sekä toimintatapoja leimaa projektikohtaisuus, mikä ennestään vain lisää vaihtelua tuotannossa. Nämä tuotannon haasteet heijastuvat osin yksittäisten asentajien työn heikkona tuottavuutena sekä suurena hukan määränä. Tutkimuksen tavoitteena on kehittää malli, jonka avulla voidaan ratkoa talotekniikan reititykseen liittyviä, usein esiintyviä ongelmia, sekä hallita vaihtelua linjasaneerauskohteen tuotannossa. Malliin on tarkoitus kerätä ja muodostaa vakioituja toimintaratkaisuja, joilla yleisiä reititysongelmia voidaan hallitusti ratkaista eri linjasaneerausprojekteissa.

Tutkimusmenetelmänä työssä hyödynnetiin konstruktiivista tutkimusotetta, jossa käytännön ongelmaan pyritään kehittämään ratkaisu teoreettista tietämystä hyödyntäen. Menetelmä edellyttää tutkijalta aktiivista osallistumista, kohteeseen vaikuttamista sekä havainnointia. Ensimmäiseksi, rakennusalan tuotantoon ja sen haasteisiin perehdyttiin kirjallisuuden sekä neljän linjasaneerauskohteen pohjalta. Hankitun ymmärryksen pohjalta luotiin vakioitujen toimintaratkaisujen malli, jota testattiin käytännössä linjasaneeraustyömaalla. Kehitetyn mallin vakioidut toimintaratkaisut koostuvat yksinkertaistetusti eri työsuoritteista, joilla voidaan toteuttaa talotekniikan (viemäri, vesi, sähkö ja ilmanvaihto) reitityksiä erilaisissa tilanteissa huoneistotasolla.

Mallin testauksesta saatujen tuloksien perusteella voidaan todeta, että linjasaneerauskohteessa tehtävää työtä voidaan määrittää huoneistotasolla etukäteen hyvinkin tarkasti ja luotettavasti vakioitujen toimintaratkaisujen avulla. Täten talotekniikan reititykseen liittyviä ongelmia voidaan hallita huoneistotasolla entistä tehokkaammin. Toisaalta tuloksista voidaan myös päätellä, että linjasaneerauskohteessa tuotannon kannalta muita kriittisiä tekijöitä ovat työn aikataulutus ja rytmittäminen, sekä työmääräimet, joilla yksittäisten suoritteiden sisältö voidaan määrittää tekijälle tarkemmin. Kehitetyn mallin avulla, tulevaisuudessa voitaisiin vaikuttaa myös esiin nousseisiin haasteisiin.

Avainsanat Vakiointi, toimintaratkaisu, suorite, linjasaneeraus, tuotanto, prosessi

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Abstract

Construction production consists of complex processes which take place in dynamic environment. Processes like this contains vast amount of variability which complicates management and efficiency of production. Moreover, practices and procedures at construction sites tends to be rather unique and project-specific. That only increases amount of variability in production. These issues in production reflects partly as low work productivity of single installer and huge amount of waste. Objective of this research is to generate a model that could be utilized to solve problems concerning routings of building service systems and control variability in pipe renovation production. Intention is to gather and construct standardized solutions for solution model to tackle frequent routing problems in apartment level on pipe renovation projects.

This research implements constructive research approach, in which practical problems is intended to be solved by new construction utilizing theoretical knowledge. For researcher, constructive research approach requires active participation, manipulation of inspected object and observation. In first phase, comprehensive understanding of construction production and its challenges was gained by inspecting literature and four pipe renovation projects. The constructed model of standardized solutions was based on the obtained understanding. Model was tested in practice at pipe renovation site. Standardized solutions of constructed model consisted of separate tasks which can be implemented to execute building service system (sewer, water, electricity and ventilation) routings in different situations on apartment level.

Based on the results gained from testing of model in practice, it could be stated that forthcoming work in pipe renovation project could be determined beforehand quite accurately and reliably on apartment level by standardized solutions. Thus, problems concerning the routings of building service system could be handled more effectively than before. However, from the same results it could be deduced that other critical factors concerning the pipe renovation production are scheduling and pacing of work, as well as task descriptions, that could provide more accurate information about content of certain task for installers. Nonetheless, with the constructed solution model, it could be possible to affect these risen challenges in future.

Keywords Standardization, solution, task, pipe renovation, production, process

Alkusanat

This thesis has been done for Aalto university´s school of engineering with Fira Palvelut. Advisor of the thesis was Jaakko Viitanen from Fira Palvelut Oy and supervisor of the thesis was Antti Peltokorpi from structural engineering department of Aalto university.

Topic of the research was decided with development department of Fira Palvelut. Objective of the research was to find solutions to low productivity of work in pipe renovation projects. Solution to low productivity was approached with possible opportunities to standardize functional operations on pipe renovation sites. This research required deep collaboration with site management.

I want to thank my advisor Jaakko Viitanen from Fira Palvelut for guidance, discussions and sparring. I also thank Otto Alhava from Fira for interesting and challenging topic, and especially for encouraging to think and create something new. I thank my supervisor Antti Peltokorpi, whose guidance helped to set the focus during the research. I thank Aki Kuittinen from Fira Palvelut for collaboration on renovation site. I also thank Fira Palvelut for financing of the research. Finally, special thanks for my family and friends for supporting and listening.

Helsinki 19.11.2017

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Table of contents

1 Introduction

1.1 Background

Development on construction field has been remarkably low on last decades. Problems on construction industry are many. Most apparent problems manifest as weak productivity, high amount of waste, project based thinking and different objectives of separate actors of project. (Bertelsen and Sacks, 2007). These problems are partly reflected as unproductive work of labor at construction site. However, the labor is not one to blame for low productivity alone. Prevailing circumstances and procedures in construction field seems to cause major disruptions for productive work of labor.

This research focuses on investigating and improving productivity in pipe renovation project. Pipe renovations are especially awkward from productivity perspective for their complex processes and dynamic production environment. Reasons for these two problematic features are not that trivial or obvious.

Currently, one significant factor is a notable role of subcontractors on projects. Collaboration of general contractor and subcontractor has a direct impact to a success of a project on different levels and perspectives. However, the collaboration is far from optimum at the very moment. Sacks (2016) points out an unfortunate situation as general contractor has neglected the responsibility of production and left it entirely for the subcontractor. In lack of help and support subcontractor usually just try to manage best they can. Too often prevalent intention is just to shift the risk and responsibility to other stakeholders. These kinds of arrays and hostile environment are apt to create unnecessary dissensions and contradictions among different actors of project which in turn decrease productivity (Dave *et al.*, 2008).

Previous example represents insufficient collaboration of operating actors at construction site and its negative influences to projects. As considering the interaction between general- and subcontractor, the other issues are also poor communication, lack of common unambiguous protocol for operating and deficient transparency and reliance (Loosemore, 2011). On the other hand, Sacks (2016) states the general contractor major reasons for subcontracting are first, decreasing risks rooted to vagaries of the economy which exist in having own employed workforce such as certain specialists whose contribution is not needed constantly and second, opportunity to transfer risks to other stakeholders. Seems like avoiding certain problems have generated new problems and these new issues have not been considered properly yet. Altogether, complex and contradictory relationship of project groups generates challenges for productive operating.

Pipe renovation field retain some common main principles as new construction field but it also contains some unique requirements distinct from other fields of construction. For instance, demolition work has a significant role in the beginning of renovation phase. Some old structures, sewer- and plumbing systems are usually demolished out of the way in order to renew the building service systems. During demolition phase, conventionally some unpleasant factors occurs as actual state of the structures of building reveals. These factors are often manifested as dimensional problems such as inadequate cross-section area or volume of ducts or actual location of ducts. Dimensional problems are usually result of changed building requirements over time. New building service systems requires more space (for example due to thermal- and sound insulation and fire safety requirements) than at the time these old buildings were constructed. Also, hazardous building materials such as asbestos causes problems during demolition phase by decelerating and limiting outcomes (Bryde and Schulmeister, 2012). Unstable working environment creates its own issues concerning predictable and efficient production.

Other typical requirement for pipe renovations is relatively short lead time of renovation phase. Thus, the declarative outcomes may cause a vast damage to a pipe renovation project. To simplify the nature of pipe renovation project it could be expressed as follows – the main intention is to demolish the old building service system as needed and replace the new one as fast as possible. Working under constant rush may consume lots of energy and cause stress for actors at renovation site.

In pipe renovations, one major uncertainty factor for general contractor are the initial plans. These plans are usually drawn up by engineering office which are purchased by client as a separate entity via price competition. Low price has probably the most pre-eminent impact to selection of designer. Altogether, these low budget-plans are usually rather approximate and interpretative than complete and unambiguous. Thus, general contractor should operate with great uncertainty as plans may include flagrant defects that may occur too late and interfere production (Bertelsen and Koskela, 2004).

Above mentioned issues in pipe renovations seems to manifest as poor value adding performance of one assembler or trade crew. During one workday, too much effective working time is wasted as there are too many uncertainties of what should be done and how it should be done. This waste of time correlates directly to productivity of workers` work at pipe renovation site. Problems are also critically related to information management, since many obstacles originate for the reason that operating actors do not have enough or requisite information to perform effectively.

1.2 Objectives

Main objective of this research is to clarify how operational performance could be improved to increase productivity of assemblers in pipe renovation projects. To achieve that goal, we should understand *how* to perform more effectively in different situations and with different border conditions. Renovation projects are implemented to fulfill different needs of customers. Thus, primary task is to figure out the most effective ways to fill those needs. Our objective is to survey the possibilities to standardize effective solutions and produce a prototype of "solution model". This prototype should contain standardized solutions for recurrent routing problems that occur from project to project.

So, the research questions could be phrased as:

1. What are the operational characteristics of pipe renovations?
   1a) What are the needs of customers that should be fulfilled frequently?
   1b) What are the components that enable the fulfillment of the needs?

2. What are the fundamental issues hindering operational performance on pipe renovation site?

3. What are the standardized solutions that improve the performance of operations?
   3a) How the solutions overcome the routing/installation obstacles and fulfill the customer's needs?
   3b) Which crucial tasks these solutions include?
   3c) How solution model should be constructed and implemented?

At this point it is relevant to decipher these above-mentioned questions as well as define the presented concepts. Considering this research, it is important to understand - what are the actual objects that should be concerned in pipe renovation context. We must clarify the factors that we are dealing with. Therefore, *needs* of customers are considered as different required outcomes of renovations such as renewing domestic water pipes to a washbasin cabinet in kitchen, sewers and floor drains to a bathroom or data and antenna socket to a living room - what are the actual needs of customers. *Components*-, instead, represent the physical goods such as sewer pipe, water pipe, electric cable and socket that are necessary to enable those final results.

To understand factors affecting the installing work at site, potential obstacles should be investigated and detected. These obstacles determine the physical restrictions that should be tackled. Potential *obstacles* are regarded as factors that complicates or prevent the installation of a specific component. Also, hazardous materials (e.g. asbestos) are considered as obstacles since they cause specific extra treatments.

Finally, in this context *solution* means a compilation of distinct tasks that provide the fulfillment of certain need – e.g. how the sewer pipe is routed from washbasin cabinet to vertical drainage line or electricity cable is routed from the device to a distribution board. Thereby, single *task* is considered as one deliverable such as drilling a hole to a wall, demolishing old structure, routing a sewer pipe, installing drain or covering a floor. Final sub question (3c) concerns how the constructed model should be structured, connected to its environment and implemented in practice.

1.3 Research scope

Boundaries of this research are set for detecting and defining the solutions and the tasks that constitute these solutions. Therefore, this research does not intervene on the process of gathering the information or quality controlling. These concerned solutions are only one part of entire pipe renovation production, in other words, many processes and actions have an affection to these solutions as well as these solutions influences several other processes like material acquisitions and resource allocation. However, it is crucial to set these boundaries in order to set the focus. This research could not resolve every existing problem on the field at once.

1.4 Research methods

This research is implemented with constructive research approach (Kasanen, Lukka and Siitonen, 1993) Hereby, we are coupling with practical issue and trying to resolve the problem by creating an operational model or strategy to overcome the issue. Theoretical knowledge generates the background to the operational model which must also be tested and validated on field to prove its functionality, not only theoretically but also in practice. Constructive approach characteristically manipulates and affects actively the observed object, not only monitor it passively (Lukka, 2001). So, in this research selected approach manifests as active dialogs and perception sharing with involved actors of pipe renovation projects.

Purpose is not to create completely new solution entities, but rather to survey and gather data to understand which solutions are reasonable to refine and share to wider utilization. Therefore, standardization of solutions should be relevant. Comparison between effectiveness of new constructed model is intended to accomplish by comparing the performance in test project to four source projects. In this case, performance include general overview of projects´ features and survey of emerged problems. Thus, information should be gathered from already realized `sourse` projects to gain a reference data.

1.4.1 Constructive research approach

Constructive research approach aims to generate innovative constructions to solve practical, the real-world problems and in this manner, contribute the particular branch of science. Constructive research approach could be utilized quite broadly, as it has been implemented especially in business and technology sciences. All man-made artifacts, such as models, plans, organizations structures and information system models could be considered as new constructions. It is characteristic for all aforementioned notions, that they are not found already, but rather invented and developed. (Lukka, 2001)

Lukka (2000) have categorized main features of constructive research approach to be:

- Focus on real-world problems, which are proved necessary to be solved.
- Generate innovative construction to resolve original problem, that is tested in practice.
- Close collaboration between researcher and practical actors, in which experimental learning is assumed.
- Should be linked to existing theoretical knowledge.
- Empirical findings should be reflected to theoretical frame.

Kasanen, Lukka and Siitonen (1993) have illustrated elements of constructive research approach in Figure 1. Focus seems to be in solving practical problems with theoretical leverage and contribution. As emphasis is more on problem solving than describing phenomena, utility in practical frame like construction production should be relevant. Also, as earlier mentioned, the focus of this research is more in solving practical problem than generating theoretical contribution. Therefore, in this research, primary focus is set on the first four above mentioned features.

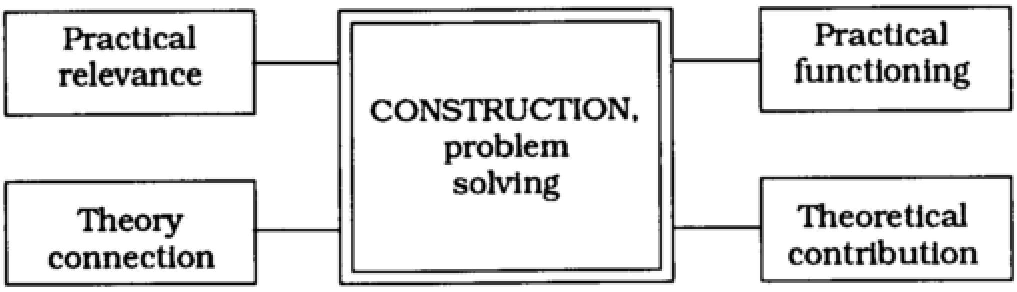

Figure 1 Elements of constructive research approach (Kasanen, Lukka and Siitonen, 1993)

Ideal result of constructive research approach would be outcome where practical problem is solved and the research process has generated significant contribution to both practical and theoretical fields. Attempt to create new construction and test it in practice, enables chance to apply, try out and develop existing theories concerning structures and process in practice.

However, in theoretical perspective, even somehow unsuccessful project may provide some valuable information. On the other hand, project without any significant theoretical contribution may provide new interesting and functional application based on existing theory. (Lukka, 2001)

Implementation of constructive research method could be rationalized first, by the relevance of research theme. In some cases, insufficient practical contribution of academic researchers is discussed. In constructive research approach, significance of research theme is considered in first by both aspects – theoretical and practical. Thus, the relevance of subject is revealed immediately. Another valuable feature is that constructive research approach does not provide only neutral academic description of the phenomena or explanation deduced from survey, but it also enables utilization theoretical tools for practical problems. Researcher should import existing theoretical aspects and knowledge to process, which tend to be constraint/bottle neck for more pragmatic actors. (Lukka, 2001)

In this research, the intention is not only in observing and diagnosing the object by scientific manners. Intention is rather to solve the practical problems utilizing scientific methods. However, theory do not provide the only frame to inspect the topic. The practical perspective is clearly included to the frame of this research by inspection of renovation sites and active participation in test project.

Positive features considering constructive research approach could be expressed to be critical observation and analyze of relevant theme with solution oriented approach, possibility to build bridge between theory and practice, cooperative acting with target organization. Potential risks with this research approach could be, too sensitive findings to publish from target company perspective, unworkable collaboration and situation where researcher should balance with commitment and neutrality during process. (Lukka, 2001)

Considering this research, constructive research approach permit focusing in practical problem. Topic is also observed comprehensively in practice and theory. Observation phase may shift the initial thoughts of problem and nature of it as the understanding of topic evolves. Finally, new construction may give impetus for new comprehension or system that could be implemented and improved even further. However, changes in the construction industry frame tends to require time and persistence. So, composure might be obligatory.

1.5 Structure of the research

The research is divided in five different phases (Figure 2) adapting Kasanen, Lukka and Siitonen (1993) model of constructive research approach. In first phase, practical problem is identified and defined which is the poor productivity of labor in pipe renovation sites. In second phase, to understand the very nature of the complex situation the comprehensive knowledge is required to be obtained about the topic. In third phase, focus is directed to construction of solution model based on theoretical knowledge and innovative insights from field. The fourth phase could be considered as validation phase as the constructed model is intended to put in practice i.e. test the solution mode on pipe renovation site. Also, functionality of the constructed operational model should be analyzed and compared to reference values which are gained from previously realized projects. (Kasanen, Lukka and Siitonen, 1993)

Figure 2 Structure of research

So, focus on the second phase is in obtaining broad understanding of the subject (Kasanen, Lukka and Siitonen, 1993). The information should be gathered from several locations to ensure wider comprehension. In this instance, information sources are field i.e. pie renovation sites to bring pragmatic aspect, literature to provide theoretical perspective, renovation plans to understand basis of operation plans as well as the quality of information that renovation plans contains.

In the third phase, generating phase, the operation model is constructed based on theoretical knowledge and practical factors. Purpose is to utilize already existing knowledge of processes, flow and standardization and connect the practically effective operations to it. By that, functional model for practical problem should be constructed. The theoretical knowledge is gathered from literature i.e. from theoretical frame of references. In turn, practically effective operation solutions are gathered from field. Other way to gather solutions is to analyze renovation plans and gather the functional solutions from there, as well as monitor the operating pipe renovation sites to identify which solutions works well in practice.

As the solution model is constructed, it is tested in practice by implementing it on pipe renovation site in the fourth phase. Functionality of model is tested in sixteen apartments. After the testing, gained data is analyzed to validate the functionality of constructed model.

In final phase, whole research is analyzed profoundly. For this is a master thesis, the emphasis is in solving an industrial problem rather than producing a scientific contribution. So, in a way the research method could be considered as applied constructive research approach.

2 Characteristics of pipe renovation field in Finland

In this chapter, the current state of pipe renovation field in Finland is observed. Intention is to survey what kind of features, trends and offset are reign at the moment, but also in the near future. Objects under inspection are volume/demand of pipe renovations and typical features of buildings in which pipe renovation is about to come.

In this research pipe renovation is defined as property's refurbishment work of building service systems. In addition to this, during pipe renovation it is possible to accomplish other repair projects of property such as renovation of bathrooms, kitchens, staircases and common spaces. However, scope of renovations should be considered project specific. Characteristics that increase complexity of pipe renovation project are thought to be issues concerning original plans, features of exciting building and residents of building. Problems with original plans manifests as fallaciousness of plans – building has not been constructed according to the original plans – or as total absence of original plans. Problems with features of buildings emerge if apartments are modified by the resident. These modifications may concern use of rooms, locations and routings of building service systems or new surfaces built over old surfaces. Due to these factors, quality of project plans has significant matter considering success of project. Moreover, every now and then some residents are also willing to live in their apartments during renovation phase. Demand to maintain some apartments of building habitable during renovation phase creates its own challenges. (Paiho *et al.*, 2009; RIL 252)

2.1.1 Current state of pipe renovation field

Apartment houses have been built in Finland since 19th century. Rest rooms in apartments, built during that era were relatively poor in quality and thereby pipe renovations have been accomplished every now and then during last decades. However, construction boom of apartment houses started in 1960 and continued with buoyant trend until the end of the 70´s. Between 1960 – 1980 approximately 47 percent of the current apartment buildings in Finland were constructed. After that period, amount of construction has little decreased, but about 82 percent of Finland´s apartment houses have been built after 1960. Figure 3 presents the quantity of constructed apartments in Finland during different decades. Original reasons for increased number of apartment houses were poor living conditions of apartments at that time and migration from countryside to cities. (Paiho *et al.*, 2009; RIL 252)

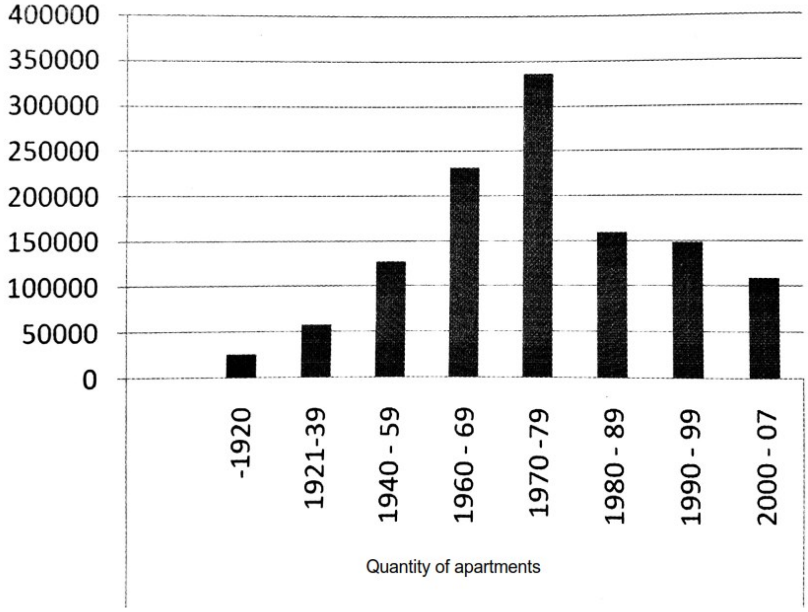

Figure 3 Constructed apartments in Finland on different decades (RIL 252)

Demand of pipe renovations started to increase in mid-90´s since pipe systems of buildings constructed in 1960 began to require repairs. Since then, demand of renovation of pipe systems has increased linearly. Demand for pipe renovations tripled from 2000 to 2010. Assumed life time of one pipe system is estimated to be around 50 years. Due to this, highest peak in demand should emerge in 2020 as huge amount of apartment houses built in 70´s requires renovation of pipe systems. Paiho *et al.*, (2009) have estimated forthcoming demand for pipe renovations as Figure 4 demonstrates. Highest peak should be around 2025. Moreover, since 2010 there have been more installation works in pipe renovation field than in new construction field. (Paiho *et al.*, 2009; RIL 252)

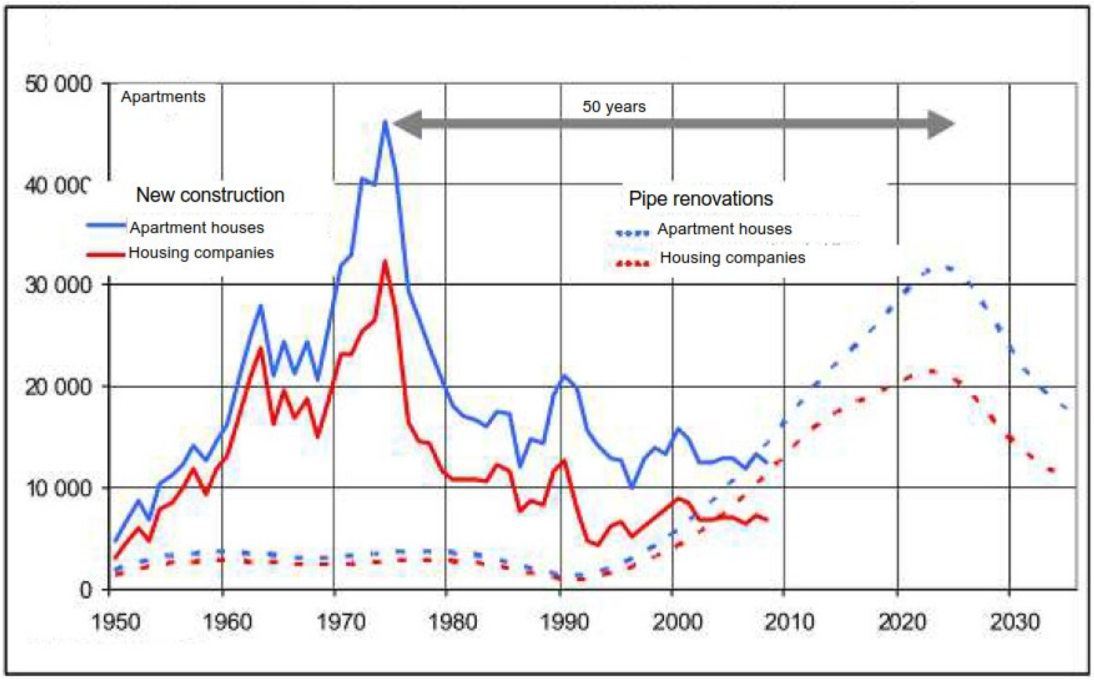

Figure 4 Solid line presents constructed apartment house apartments per year until 2008. Dashed line is prediction of pipe renovation trend in future (Paiho *et al.*, 2009)

It can be assumed that pipe renovation field provides vast amount of work in next 20 years. Thus, it is reasonable to elaborate and develop more effective methods to provide better services for customers because there will be demand.

2.1.2 Features of buildings and projects

This section observes typical technical features that one pipe renovations project generally contains. Typical solutions of structures and building service systems within 60´s and 70´s constructed buildings are also inspected. In this manner, comprehension of average environment of production is obtained. On the other hand, familiarization of typical project provides impression of general measures that are utilized in practice.

Operations in pipe renovation project could be divided into four groups. These groups are categorized into operations concerning:

- Water, drainage and heating systems
- Electricity supply systems
- Ventilation systems
- Construction works

Features and contents of each category is observed next. First notion is that the trend during 60´s and 70´s was to design building service system according to ´disposable-building´ protocol (RIL 252). Thus, life span of one building was decided to be from 25 to 30 years. Because there was no intention to refurbish these buildings back then, many building service systems are embedded into structures. This procedure creates its own border conditions and challenges considering the methods and measures implemented in pipe renovation projects.

Seems like that decision made at that time have complicated the procedures in which pipe renovations should be carried out today. If design and construction solutions by then would have been considering the compatibility of forthcoming renovations, even little, situation could be quite different now.

Principle of implementation for water and drainage systems varied according to structure of intermediate floor and bathroom. Traditionally vertical pipe lines were placed in flue clusters. These ducts were produced either in situ or from pre-fabricated concrete flue-elements. If load bearing intermediate floor was casted in situ, horizontal pipe routings were embedded into that structure. In prefabricated intermediate floor structure, horizontal pipe routings were installed in lower floor ceiling. Generally used heating system was two-piped water radiator system. Life span of this central heating system is estimated to be from 50 to 100 years. Therefore, the measures concerning heating systems during pipe renovation project are usually limited in renewal of radiator valves and system adjustments. (RIL 252)

Apartment houses are connected to electricity distribution network by connection cable. Connection cable is routed underground to main switchboard of building. Main switchboard of building usually locates in basement. From the main switchboard, electricity is distributed by risers to each apartment´s own switchboard which locates usually in vestibule. Routes of risers were generally embedded in walls of staircases. From apartment´s own switchboard, electricity is distributed to each room. These electricity routes in apartment were placed inside partition walls and intermediate floors or carried out as surface installation. However, electrification of these old apartments is inadequate compared to current requirements and demands. Therefore, renovations concerning electricity range over whole electricity system of building. (RIL 252)

During 1960 and 1970 ventilation system of apartment houses were basically executed by implementing two methods – forced exhaust ventilation and natural ventilation. In mechanical forced ventilation system, apartments on top of each other could utilize shared ducts. This method also requires less surface area, as every apartment do not need own ventilation ducts. Engine room of this ventilation system is generally placed in attic or roof. Natural ventilation was utilized in apartment houses consisting of three or four floors. In this method, every space demands its own duct, which requires also more surface are. Exhaust valves were located in kitchens, bathrooms, toilets and walk-in closets. Exchanging air was get from slits in window seals (leaks). Ducts were constructed out of either concrete or metal plate. Significant difference between these two materials is that in concrete ducts, emerge of air leaks are quite common in longer run. These tightness problems may interfere effectiveness and functionality of ventilation system. (RIL 252)

Construction works could be concerned to present every structure related works that contributes the renovation of old building service system. These works are for instance demolition works, repair works and all sort of construction works from tiling to installation of kitchen cupboard. During pipe renovation, it is quite common that surfaces of basements and staircases are also renewed. Other popular solution is refurbishment of common sauna department.

There is more than one method/strategy to execute the repairing operations to abovementioned building service systems. In RT-instruction manual 92-10913 (2008) these techniques are determined and divided to five different methods:

1. All the old structures, pipes and cables are demolished and thereafter renewed. This method is suitable if old structures are somehow damaged (e.g. mold, moisture) or intention is clearly to improve quality of property.

2. New pipe systems are placed in old locations. In that case, old structures/ducts are opened in the extent of necessary (usually one or two sides of duct is adequate) and old pipe systems are demolished out of the way. This method is particularly functional, if old ducts are located reasonably and easy to open/operate.

3. Old structures and pipe systems are left to their old locations and not demolished at all. New pipe systems are placed into new ducts and capsules which are constructed in new locations as well. This method is suitable, if there is enough room for new routes (vertical lines in staircases for example) or old building service system should operate during renovation.

4. Existing structures and pipes are left unchanged like in method number 3, but new vertical lines are constructed by implementing prefabricated duct-elements. To implement this method effectively, dimensions of structures intentioned to utilize should be accurately inspected and diagnosed.

5. Coating of old pipes. Cast iron sewer pipes are coated with plastic mass. Water pipes are coated with epoxy-resin mixture. Vertical sewer lines and bottom drains are

treated with plastic coated polyester felt. Also, combinations of abovementioned coating methods are applicable. With coating methods, several demolition works could be avoided and operating might be faster and less expensive. However, there is not enough experience of long term durability of these coating methods yet.

In choosing right renovation method, factors that have influence to a decision making are structural solutions of building, condition of building service system and determined level of quality and budget (RIL 252). It could be stated that every method contains its pros and cons. Meaning of these factors (pros and cons) also depends on eye of the beholder. For example, effective method for installer might not satisfy customer´s demands of aesthetics, but on the other hand, solution with better quality takes usually more time and money. Thus, to gain satisfying and reasonable method, several factors should be considered.

3 General features and challenges of construction production

This chapter introduces the investigated problem. Intention is to explore the predominant challenges concerning construction production more profoundly to understand the true nature of it. Therefore, to gain more comprehensive understanding, broad observation of topic is more proper than very strictly limited inspection.

3.1 State of construction production

Productivity in construction industry is low (Koskenvesa, 2011). Also development of productivity in construction industry have been slow (Paasanen, 2010 pp. 17 - 18). Poor development and high costs force construction industry to search new methods to enhance productivity (Koskenvesa and Sahlstedt, 2011). In addition to slow development, construction industry is facing not only internal changes but also changes from external factors including: changing social pattern, internalization, growing environmental awareness, rapid development of IT sector and more aware and demanding customers, that will radically shape the circumstances of construction (Lindfors and Leiringer, 2002). General level of performance in construction production seem to be quite declined. Old manners and methods may fall behind as requirement to renew comes not only from inside the construction industry, but from outside as well. And maybe even faster.

On production level, Siikanen (2009) have investigated challenges concerning development of site production and problematic production management. Key findings from Siikanen´s (2009) research have been divided to five points:

1. Task level direction is the weakest segment of production management.
2. Content of production plans and documents are generally non-specific, so their contribution to operating is rather slight.
3. Quality of performance varies significantly between different sites and task entities.
4. Production plans and controlling measures are carried out separately and transfer of information is not systematic.
5. Documentation of quality assurances is inadequate and quality requirements concerning particular operation is not specified on documents.

From these findings, one major issue in pipe renovation production could be deduced. As content of production plans are rather general and inaccurate, task level directions seem to remain ambiguous too. Quality problems of building service plans may be due to lack of substantial information. This may leave operation plans remain quite open as well. Therefore, operating level (installers and trade crews) are left to execute their tasks whit ambiguous and inaccurate directions. This could partly explain the significant variance of performance between different sites and trade crews, as quality of performance is majorly based on expertise and skills of certain actors, not on workable production system including practical plans and directions.

Other noteworthy findings from Siikanen´s (2009) research are notions of poor monitoring in how new methods are implemented and adopted in practice and how high turnover of workers and inadequate introduction of labor create challenges over whole industry. Based on these results one problem on sites seems to be deficient operation strategy. Different management measures are carried out, but meaning of them and impact to entity is not clear or considered enough. Things get basically done without any further thought. Kauppila (2014 p. 40) assess that many documentations and measures are executed rather because of regulations than potential positive impacts to process. These findings in turn describes the issues concerning implementation of new methods. Also, dynamic working environment and common attitude in pipe renovation projects seem to create its own challenges for implementation of new methods.

As this many actions are carried out quite carelessly, consequences may also emerge in common state of mind as a loose attitude. Negligent performance becomes somehow acceptable and then, problem could be expressed to locate at culture level. Höök and Stehn (2008) have estimated that general construction project culture may influence its participants, as mentioned outcomes are:

- Low worker motivation
- Emerging problems are solved without deeper consideration and communication with other involved actors
- Implementation of ad hoc solutions and low sense of responsibility concerning tools, materials and working environment.

These results crates quite ominous impression of construction site as operating environment. However, these findings may also explain poor productivity of construction industry for their parts. It seems like poor state of one segment is partly consequence of poor condition of other segments. If we consider what causes low worker motivation, the answer hardly will be found from only one factor, but from several affecting factors with negative influences.

In pipe renovation projects, loose attitude and responsibility may cause significant problems, since the production environment is already someone's home. If the working environment is maintained poorly (breaking structures or home furniture), problems probably emerges in form of extra work and waste.

3.2 Characteristics of construction production

As construction industry is described regarding its nature and specific features, project based production, uncertainty and complexity are frequently occurring themes (González *et al.*, 2011 p. 708) . Reasons for project based orientation is explained to be result from customers varying demands that may separates one project from another, to be one-of-a-kind product which is produced by multi-skilled ad-hoc teams (Bertelsen and Koskela, 2004; Salem *et al.*, 2006). The complex nature is demonstrated as construction production consist of several features or actors that are highly interdependent and also numerous factors that have influence to these features (Salem *et al.*, 2006; Bertelsen and Sacks, 2007). Frequently as complexity of construction is highlighted, it is compared to manufacturing industry. So, would it be more figurative to express that construction industry is considerably more complex than manufacturing industry? Bertelsen (2003) claims in his research that major part of characteristics of complex system occur in construction context, as he demonstrates construction projects as characteristically complex, unique, and dynamic systems which should rely on initial design and plans that contains several subassemblies with individual specifications. It could be assumed that construction is complex industry also in general. Therefore, phenomenon in construction production should be considered as complex system requires.

One-of-a-kind production generates also its owns features. Bertelsen and Koskela (2004) demonstrates two of them to be significant role of information management and ´wicked problems´. As one-of-a-kind production could be considered to create unique products with unique design and plans, management of information is in huge role. For instance, although the actual task of certain assembler would not be that complicate to execute, absence of required information may convert even the simplest task to complicated one. Wicked problems, in turn, requires contribution and consensus of several stakeholders to be resolved which tends to be quite rigid and time consuming procedure (Bertelsen and Koskela, 2004; Elfving, Tommelein and Ballard, 2005). As can be noted, almost every feature involving construction production generates its own ´sub features´ that has its own influences to entity.

On the other hand, Bertelsen and Sacks (2007) questioned the common one-of-a-kind and isolated project thinking for there are constantly somehow similar projects in progress at the same time and thus, construction industry should be considered as ´eternal chain of interwoven projects´ since same actors (mainly subcontractors) are involved to several projects in particular economic region. This idea is admittedly true, but although some actors might be involved in more than one project simultaneously the connection remains unrealized if there is no real interaction between these actors among these projects. In other words, if there is no real interaction over projects, certain projects may remain as isolated and one-of-a-kind. Especially in terms of improvements.

To be able to develop practices in construction production, adequate comprehension of industry´s main characteristics should be obtained dos Santos (1999) claims and lists some of the most common of them to be:

- Spatial fixity of building
- On site production
- Fragmented industry
- Non-experienced clients
- High proportion of subcontractors

Construction production could be considered as temporary production in temporary location which requires establishment and dismantlement of production system i.e. construction site. Fragmented nature of industry in turn may due to the point that different firms in construction possess very different work specializations (dos Santos, 1999) and therefore multi-skilled production teams prevails (Bertelsen and Koskela, 2004). Still, separate groups need to perform in mutual environment and these groups may also requier different preconditions in locations to operate. These factors only amplify the fragmented nature. Relevance of non-experienced clients manifests in their inability to clarify their need or discernment considering the quality (dos Santos, 1999). Client could also have problems in understanding the practices and terminology of projects. These factors are apt to create misunderstandings between client and supplier. Bertelsen and Koskela (2004) highlight one significant characteristic, risen from their proposition to define nature of construction production, to be cooperation. This notion could be associated with high proportion of subcontractors, as one project involves several groups and actors. This creates the need for collaboration.

To sum up the specific features of construction and pipe renovation, most notable notions should be the project based production that produces one-of-a-kind products. The production takes place mostly on site conditions that is fixed to a certain location. The fixed location of construction site may also generate its own unique border conditions considering for example production methods, logistics and site arrangements. The performance might vary a lot depending on the actual location of site. Affecting factors are totally different in the middle of city center than in calmer suburban area. One example for affecting factor could be the available space to utilize. Thus, the offsets for certain project should be defined accurately. Cursory assumptions may provide totally distorted and misleading reflection of reality. One of the most dangerous and distorted thought is comprehend construction production to be simple. That is very misleading. Construction production is complex.

Above mentioned characteristic touch field of pipe renovation as well. It could be thought that same laws and principles hold both, construction and pipe renovation, in outline. Pipe renovation could be considered as branch of construction production as same tools, material and labor are mainly implemented. Major differences seem to manifest in emphasis of different factors such as demolition works, structure works and role of customer.

3.2.1 Comparison between construction and manufacturing

The need to compare these two industries is relevant because many innovations and practices are adapted from manufacturing industry to construction industry (dos Santos, 1999). It is the differences of these two industries that helps us to understand why direct implementation of certain practice might not function correctly in another context. However, positive contribution of standardization in manufacturing processes is remarkable (Imai, 1997). In this regard, comparison of these two industries may provide comprehension of how standardization of operations could be utilized in construction production, as it is one major objective of this research.

Imai (1997) have defined features of standards and standardization as:

- Standards presents most efficient (effective, easy and safe) manners to carry out operations
- Standards preserve the expertise and know how as intangible assets of company.
- With standards, performance could be evaluated.
- With standards, operations could be maintained and improved more effectively.
- Standards provide foundation for orientation and training of employees.

Standards should determine how operations are executed. If variation occur in processes, despite existing standards, standards should be either modified or consider - are standards determined and introduced correctly to workforce? (Imai, 1997)

Standardized operations could be utilized in pipe renovation production for above mentioned reasons and to control variability in processes. If efficient solutions to operate could be determined and distributed for company, systematic operating could be enhanced.

Salem et al. (2006) highlight some major differences between manufacturing processes and construction processes on areas of workforce, operations and quality. In manufacturing industry, working conditions, wage policies and employment security for labor is more stable than in construction industry where wages of workforce are more depending on individual skill level and experience. Also, the job security is lower in construction industry. Moreover, in manufacturing, role of one worker as well as his job description is well defined. This promotes effectively specialization of labor for certain tasks. High level experts, with experience and specialized skills, are highly regarded in manufacturing industry. In construction industry, one worker might have to carry out a broad set of different tasks during one project. (Salem *et al.*, 2006)

Also, methods for quality control vary between these two industries. In manufacturing, process control is related to quality aspects by defect prevention, monitoring and interventions. In construction, product conformance is generally related to quality, as specifications, drawings and regulations determine quality standards and quality assurance is executed in collaboration of construction company and owner (Arditi and Gunaydin, 1997). Rework is also concerned differently. In manufacturing, rework is indeed avoided. Defective parts are sometimes rather decimated than fixed and new one parts reproduced, to avoid rework. In construction, rework is considered differently since only one, not replaceable, product should fulfill the requirements to be delivered. Therefore, rework is common practice in construction industry. Differences in operations and supply chains are also prominent. In manufacturing industry, operations could be accurately determined and sequenced in advance, and purchase plans are not changed for the lightest reasons. In construction, supply chain is not that rigid and due to longer production times, sequence of operations could be modulated if unforeseen exceptions emerge. (Salem *et al.*, 2006)

It seems like manufacturing industry involves more controlled manners as improvisation and make do operating is truly attempted to be diminished. Regarding to that, Bertelsen and Sacks (2007) claims that the major distinguishing element between other manufacturing and construction is the huge variation in project outcomes of construction, and as a result of this variation, every construction project requires a setup of new production process with new production system, which is eventually dismantled during the production phase. It could be thought that every construction project includes some unique features that have impact to a production system. As these features varies from previous projects, new features are easily considered as distracting ones. However, these new features could also be comprehended as potential opportunities, if these features are handled properly. This kind of orientation may enhance performing, as production system seems to reconfigure from project to project. It is more important to determine - what are the options that we can do, than just make a list of what we cannot do.

3.2.2 Product process matrix

One way to illustrate different production and business strategies is Hayes and Wheelwright (1979) product-process matrix. The matrix consists of two axes. First axis represents process structure from jumbled flow to ideal continuous flow. The other axis represents product structure from low volume to high volume. Diagonal line of the matrix illustrates the actual products via example product such as commercial printer and heavy equipment, as Hayes and Wheelwright (1979) proposes that all manufactured products settle approximately on diagonal line. As the diagonal line illustrated the actual product of the system, Schmenner (1993) updated product-process matrix to project the production system on diagonal line (Figure 5). This may provide better comprehension of the nature of certain process.

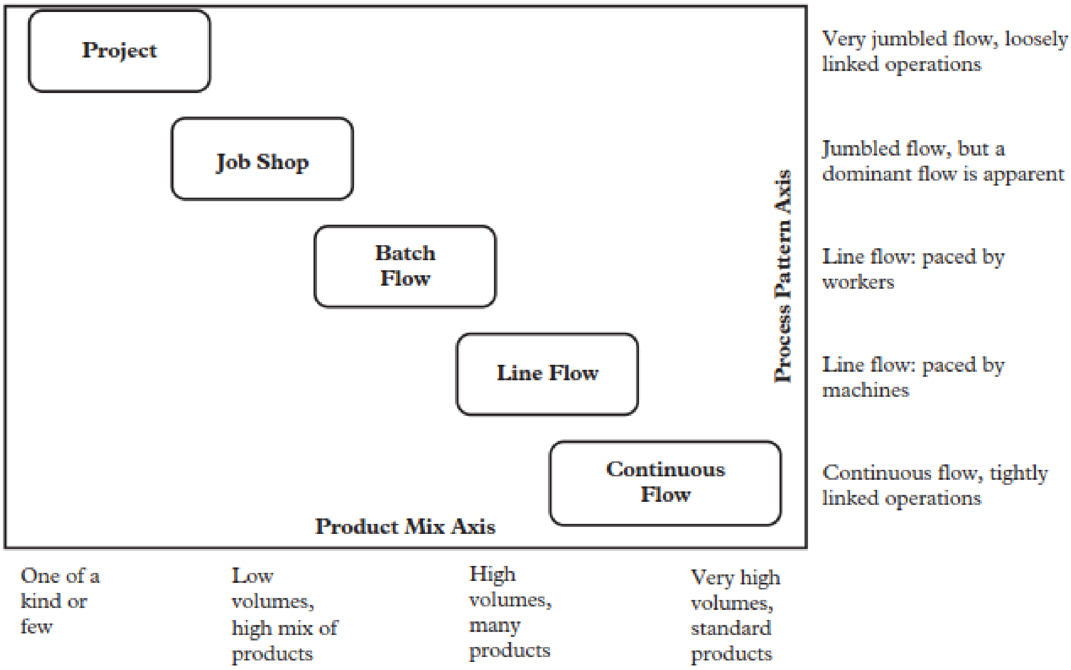

Figure 5 Product process matrix (Sacks, 2016; Schmenner, 1993)

One perspective of production system in construction industry could be determined by Schmenner´s matrix. Prevailing idea of construction industry´s project based production, locates production to upper left corner. This means very low standardization of products, and very jumbled flow with loosely linked operations on process level. However, Sacks (2016) questions this quite sketchy thought as the production systems in construction are not that obvious. Intractable production and unique project based products may have affected the mental level and awkward production may have become self-fulfilling prophecy. With more profound inspecting, it could be noticed that on certain level of abstraction, one construction project consists of different spaces. Different spaces contain some unique characteristics and requirements but however, lots of similarities as well. Due to these similarities, the production systems may not be that project based as thought, and processes should not be consider that jumbled. (Sacks, 2016)

Subcontractors, for example, tend to provide and perform quite similar products and operations from project to project, which do not resemble project based operating that much but, rather line flow (Figure 5) production system (Sacks, 2016). So, does the major variation occur actually in operations or in environment? In context of pipe renovation, it seems like the operations and tasks remains quite the same but the external factors create the demand for applied activities which generates variation for processes.

Sacks (2016) also claims that the production processes (in terms of product-process matrix) in construction projects are not homogenous, which means that different work phases and operations have different location on the diagonal line, and thus, different production flows. It is misguiding to assume that every operations share same principles and challenges. Different work phases/operations should be considered one at a time, to gain comprehensive understanding of main issues and opportunities embedded to different work phases/operations. The reign assumption that everything in construction production is jumbled, difficult and chaotic may somehow distort our conceptions and perspectives of construction production.

3.3 Productivity challenges in construction

Low productivity on construction industry is due to many different problems that manifest in different phases, fields and levels. The issue is even more fundamental as construction industry has left behind in process standardization and automatization compared to other industrial sectors. Besides this, implementation of technological tools and innovation has also left to a lesser extent. Need for profound orientation towards innovative and efficient operating is evident, as the industry aims for better competence and sustainable growth. (Dave *et al.*, 2008)

To understand dynamic environment and complex production, reasonable attempt is to model and categorize these issues. Arashpour, Wakefield and Blismas (2013) model gathers set of issues that have tangible effect to construction production. Figure 6 illustrates some focal problems with interdependences to each other. The complex nature of construction production is revealed as one factor usually have significant influence to another factor. So, to resolve the problems for example with long cycle times, the answer may not be found only observing that one factor, but also other situations like excessive work-in-process and inefficient use of resources (Figure 6).

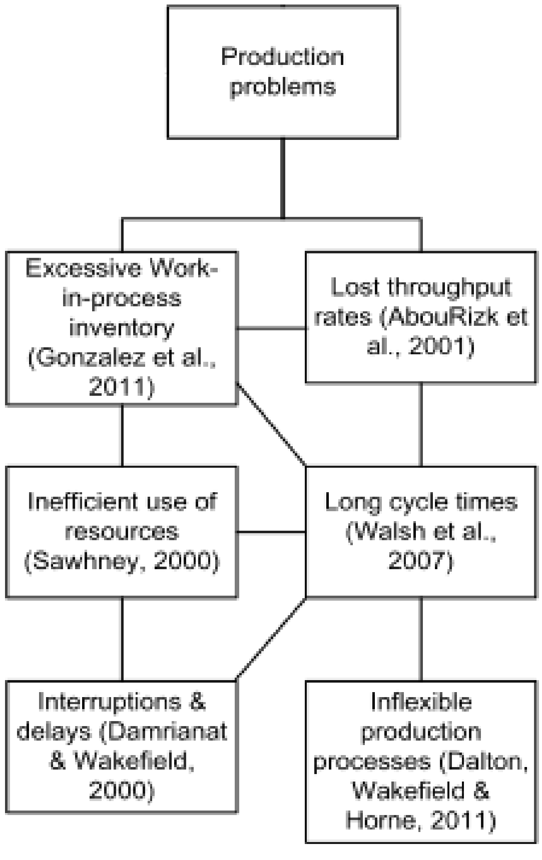

Figure 6 Set of production problems and mutual interdependencies (Arashpour, Wakefield and Blismas, 2013)

It could be stated that certain mental regression has been prevailing for a while. One issue is how these problems are concerned on the industry. Bertelsen and Sacks (2007) argue that thoughts of processes on construction industry are too simplified, as reign comprehension about processes are based on transformation perspective and alternative perspective of flow is usually neglected. Construction production should be considered as complex and dynamic system and leave the old sentiment, where unpleasant events just happen for time to time and ´let's just try to live with it´.

Radosavljević and Horner (2002) states that labor-intensive production, in dynamic environment, based on unique plans, creates unstableness to production. In this notion, considerable effect of human nature is highlighted. It is different to implement machine-orientated manufacturing than production executed by human force. In construction production, human errors might be much more common.

Intention of this research is to observe and resolve issues occurring in operational phase i.e. renovation phase. At this state and level, the problem itself may be seen narrow-mindedly as unreasonable low productivity of worker on site. The situation must be observed from broader perspective to understand the root cause of problems that eventually interferes the actual installing work of labor. In this context, the number of different problems are vast and if, the main causes and roots of problems could not be found, it would be almost impossible to overcome these problems. So, as a problem, even a very little one, occurs, it is very important to locate its root cause to handle it.

3.3.1 General contractor´s role and issues in production

Usually, general contractor responds for the actual constructing, quality, budget and time. The common method to fulfill these demands is executed by procurements with competitive bidding. General contractor tender operations, work, materials and so on for subcontractors. Eventually, general contractor may gain lowest prices for distinct procurements. Schedule for production is traditionally planned to be as short as possible. Quality in turn is monitored by different quality assurance systems. (Bertelsen and Sacks, 2007)

General contractor´s challenges tend to be associate with management of entirety. Responsibility of site activities demands broad understanding of how different units perform at site. And maybe more precisely, how different units may perform simultaneously and together at site. Complexity of general contractors role is illustrated well in Bertelsen and Sacks (2007) claim, which says that, it is practically impossible for one person or organization absolutely predict or control how certain project may progress, since possibility of variance constantly exists. Role and nature of variance in pipe renovation production will be considered later.

High utilization of subcontracting has led the construction production to the point where actual production is very fragmented and thus, the predictability is even more difficult, as well as, ensuring of quality and controlling of schedule (Dalton, Wakefield and Horne, 2011; Dave *et al., 2008*) In addition to this, it is very common that general- and subcontractor´s objectives vary enough from another to prevent the effective collaboration (Bertelsen and Sacks, 2007). The contradictions are not associated only with different objectives, but with strategies of different stakeholders too. Simplistically, it could be said that the general contractor is interested in processes and subcontractors are interested in operations/task (Sacks, 2016). Tribelsky and Sacks (2011) state that the same contradiction of strategies occur also between general contractors and designers, as designer crew´s intention is in keeping their work flow steady, which may manifest as insufficient information production (plans) for one project. In their report, Koskela and Koskenvesa (2003) claims the major reasons for deviations on site are inadequate plans and poor production management decisions.

General contractor seems to struggle with vast number of different units, variables and requirements. Effective management of construction site and project requires relevant strategy and tools, but also healthy interaction and collaboration between separate stakeholders. To bridge the gap, that distinct general contractor from designers and subcontractors, new methods should be invented, to decrease confrontation and mistrust, and to contribute common benefits and better collaboration of involved actors on construction project. One main principle of solution model is based on that idea.

3.3.2 Subcontractor´s role and issues in production

To gain more comprehensive conception of construction production and productivity, the situation should be observed from perspective of subcontractor too (Chan, 2002). As have been expressed, high utilization of subcontracting on industry have raised the influence of it on undisputed position concerning success of production. However, Loosemore (2011) points out that perspectives of subcontractors have almost completely been ignored on scientific field. Altogether, the operating on site is far from optimum or even tolerable at the moment.

Construction project may seem relatively different in perspective of subcontractor compared to general contractor. Some of the issues may be shared with these two participants. However, but both still own their particular problems too, which causes the shifting of objectives. Intention is next to identify the most common problems that subcontractors may encounter on construction industry. Main themes that emerged on Loosemore´s (2011) research were:

- Relationship and trust
- Tender practices
- Project management, scheduling and coordination
- Plans
- Low innovation
- Burnout

First challenges subcontractor usually faces in bidding phase. Commonly used competitive bidding creates its own problems to trade crews, as price seems to have the biggest impact to selection. Moreover, to gain a contract, usually subcontractors have to count their fixed-price offer based on nominally complete plans. Elfving, Tommelein and Ballard (2005) have investigated the correlation between competitive bidding and lead time. One conclusion was that, the competitive bidding had negative influences to collaboration. Loosemore (2011) discloses subcontractors´ more humane thoughts about bid-shopping and its detrimental impact on trust between parties, as subcontractors are reluctant to reveal their knowledge and innovations to others.

Unclear and unworkable design and plans causes also headache to subcontractors, as workers should operate and make decisions with inadequate information (Loosemore, 2011). Also, irrelevant production schedule, based on poor plans, tends to rise up certain reluctance on subcontractors, manifesting as inefficient allocation of resources. Short resources interferes production processes directly by increasing variability of production rates and waiting times (Sacks, 2016). If plans should be observed with high criticality, operating will most likely slow down as decision making actors should consider reliance of plans constantly. Furthermore, it is inconvenient to find pertinent information from unclear plans. From unclear plans, something essential might be missed or some details could be misunderstood. This tend to cause rework. One way to manage this issue, is attempt to check over and sift plans as early as possible, i.e. before the actual operating phase starts. During operating phase, occurrence of fault in plans may interfere or even stop certain operation.

Loosemore (2011) research also revealed subcontractors' issue regarding project management and supervising, as experience and know-how of older actors may not be shifted to a younger generation. Considering this problem, it is good to understand that all the old manners and practices are not automatically good. However, it is insane to let valuable experience and knowledge go to waste, if there is an option to gather and store this knowledge for refining and implementation.

The primary concern of subcontractors was although the relationship between general contractor and trade crews, and its influences to productivity. (Loosemore, 2011). Importance of team spirit and vital interaction on site was found to be prominent productivity booster on Chan´s (2002) research, which surveyed factors influencing labor productivity. To operate effectively on site, different parties should support and assist each other's, rather than evade responsibility, conceal knowledge and pressure others with sanctions. Ideal but beautiful.

3.3.3 Interruptions and delays

Damrianant and Wakefield (2000) have categorized process hindering factors into two different categories – *delays* and *interruptions.* Delay is defined as an issue that slows down the ongoing operating, such as demolition works, but still do not prevent totally the operating. In contrast, interruption prevent carrying out the task or operation at all. Delays and interruptions have a direct effect to production as they usually decrease productivity of labor, but it is also possible that these issues may change the production system dramatically. That is because as delays mainly manifests as extended time used for certain task, the interruption of certain task may cause more complex outcomes. (Damrianant and Wakefield, 2000)

Construction project may confront various distractions, interruptions and delays. Damrianant and Wakefield (2000) have gathered quite comprehensive compilation of these possible obstacles such as weather conditions, breakdown of equipment, inefficient construction management decisions, worker illness and fatigue, inadequate training or skill of workers, rework and accidents. These obstacles are also divided in two different classes – micro and macro level issues, according to their immediate impact to operating of either single or several actors. But then, this distribution may turn up slightly misleading. Issue originally affecting only operating of one actor may later affect many other actors as well. However, by this harsh categorization, it is possible to determine cursory seriousness of potential risks that may occur during the construction projects and divide them into different classes.

3.3.4 Variability

Variability could almost be considered as characteristic of construction production. It has different forms and outcomes along a projects, but what causes the variation in processes is main question. Dave *et al.*, (2008) claims that variability in processes of construction production is almost inherent due to the dynamic nature of working environment. This proposition admittedly hold true, but at the same time, it is quite abstract in order to gain the upper hand of variability. Arashpour, Wakefield and Blismas (2013) states that variance in processes are caused by management decisions, randomness in processes and different requirements. These factors provide yet more characterized comprehension of reasons for variability.

Randomness in processes in operational context of pipe renovation could be considered as numerous manners to perform certain operation. Processes/operations in pipe renovation field are not that tightly defined. Generally, only wanted outcome is determined, not the tasks that need to be done to achieve the outcome. This may lead to the situation where one know what is wanted, but how it is done, remains bit unclear and shady. It seems like the task itself is not usually that hard to execute, but finding the right tasks for certain location causes difficulties. Especially when these tasks are determined by operational actors/site management during renovation phase. Operation planning and operating are carried out simultaneously. This hinders the possibility to elaborate the harmony or compatibility of operations to other interdependent operations. Changing one task of operation to another task, may have significantly different effect to other operations. That causes variability to processes. However, with this procedure, the renovation projects tend to be ready eventually. But what comes to efficiency or productivity, is totally different question.

Also, it could be comprehended that wishes of customer causes variability to processes, as every apartment and every room may contain some individual features. Not to mention the individual features of people. Thus, for example operations implemented in certain apartment´s kitchen, cannot automatically be expected to be suitable in upper floor kitchen, although many features may be almost similar in both kitchens. Customer may have intention for customizing his home, which naturally creates boundary conditions for operations. As customer´s wishes are taken into account, variability in processes increase.

Demands does not only come from clients. Several regulations concerning the construction production creates its own border conditions as well. Construction regulations presents the requirements (for example fire safety, waterproofing or sound insulation) for certain structures or locations that need to be fulfilled. The operations should be performed within this framework too. As different locations and structures of buildings contains different regulations that is required to be fulfilled. So, also in this case varying demands generates variability in processes. Therefore, varying demands of customers should be produced differently in different locations, because of the varying construction regulations regarding different locations. For example, wet rooms (location) possess its own regulations. Thus, customers' demands should be fulfilled within these wet room specific regulations. Moreover, different structures, such as load bearing wall and lightweight partition wall, are under different regulations. These regulations should be regarded if customer wants for example tear down walls, shift or modify doorways, or if structures should be perforated for building service routings.

Environment (existing building) where operations are carried out generates its own restrictions (Bryde and Schulmeister, 2012). In pipe renovation context, existing building dictates strictly what should be done and how it could be done. Reasonable solutions for operations are not that numerous. In many cases, lack of space becomes a problem as new building service system tends not to fit in the planned places such as in existing ducts. Also, location of certain structures, like ventilation ducts or load bearing beam, determines how new building service systems could be routed and installed. Building´s features, such as ventilation system, which is usually either natural or forced ventilation system, generates different boundary conditions that should be considered in selecting operations.

In this context, considering renovation phase in pipe renovation project, three main sources of variability affecting the operations could be determined to be: wishes of customer, construction regulations and individual features of building under renovation (Figure 7). These demands generate the boundaries for how operations should be planned and carried out.

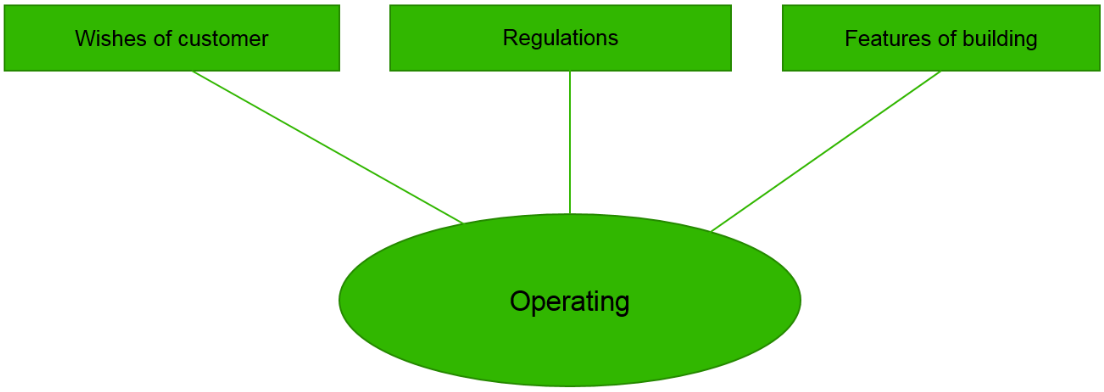

Figure 7 Three main sources of variability for operations in pipe renovation project

4 Production models in construction

This chapter is literature review of theoretical models of production in construction. Intention is to survey prevailing theoretical doctrines to obtain understanding of how construction industry is comprehended on production level.

4.1 Lean construction

Lean construction concept could be considered as coalition of researchers developing construction industry in its own frame. To get idea of this concept, its different phases should be observed. Studies shows, that one uniform definition for the lean construction concept is not unambiguous (Koskela *et al.*, 2002; Bertelsen and Koskela, 2004; Kalsaas and Bølviken, 2010). One main theme is to consider construction processes as flow of work that creates value for a customer (Bertelsen *et al.*, 2006). Anyway, it could be thought that several orientations and practices take place under lean construction. Bryde and Schulmeister (2012) have even described lean construction as fuzzy concept, for its wide scope. However, to understand current state of construction production, lean construction cannot be ignored.

As considering the development of lean construction, Bertelsen and Koskela (2004) stated that concept lean is basically a western version for Japanese production philosophy utilized in manufacturing context. But as the prevailing principles in manufacturing and construction are different, concept of lean should be comprehended as two distinct notions. Similarities however exists, but still, it is more relevant to consider these as independent concepts. Koskela *et al.*, (2002) demonstrates lean production to be rather theoretical source of inspiration for lean construction theories. Lean construction incorporates two different research streams including the practical stream and the theoretical stream. However, these two orientations/streams interacts as lean construction principles and practices are observed and developed. (Bertelsen and Koskela, 2004)

Under the practical stream, several methods and practices are developed for construction management, as Ballard´s (2000) Last Planner System (LPS) for production control could be considered as foundation and milestone of the practical orientation (Bertelsen and Koskela, 2004). Koskela *et al.*, (2002) even claims Last Planner to be one of the core ideas of lean construction. Main themes of the LPS revolve around predictability and reliability of the production or as mentioned - work flow.

One significant achievement in theoretical stream could considered to be Koskela´s (2000) theoretical model of construction production (Bertelsen and Koskela, 2004; Kalsaas and Bølviken, 2010). Koskela´s (2000) theory considers construction production consisting of three different concepts including transformation, flow and value (TFV) which should be managed simultaneously. He opens these three concepts as follows. Transformation reflect the relation of inputs and outputs – from raw material to end products – and tasks that accomplish the transformation. Flow instead illustrates the production method where intention is to eliminate different embodiments of waste or non-transformation stages in processes. Value is related to determination of customer´s needs.

As flow in TFV context is presenting events of production process, Koskela (2000) have determined six main principles to achieve ´flow´ or sound production:

1. reduce the share of non-value adding activities i.e. waste
2. reduce lead time

3. reduce variation
4. simplify
5. increase flexibility
6. increase transparency.

In addition to this, Koskela (2000) claims time to be most relevant unit to measure flow. He validates this choice by claiming that decreasing of time of processes should simultaneously reduce costs and increase level of quality.

Insights from Koskela´s (2000) research, that could be pointed up, are consideration of production as flow, role of time in processes as reduction of time could have direct positive correlations to production, and claim that transformation perspective alone provides too narrow and simplified comprehension of construction production.

Lean construction seems to embrace even quite reformative ideology in generating new lean based production system (Lean Project Delivery System) to replace traditional production system, as Koskela *et al.*, (2002) presents. Principles of these two systems are compared in Table 1. Prominent differences between these two systems could be noticed in amount of collaboration, scope of perspectives and willingness to learn and improve. Disclosing of these issues helps us to understand the prevailing problems in construction production. Bertelsen and Koskela (2004) emphasizes that complex production system requires new and more developed management approaches where cooperation and continuous learning will take center stage.

Table 1 Principles of lean project delivery system and traditional system (Koskela *et al.*, 2002)

Lean	Traditional
Focus is on the production system	Focus is on transactions and contracts
TFV goal	T goal
Downstream players are involved in upstream decisions	Decisions are made sequentially by specialists and 'thrown over the wall'
Product and process are designed together	Product design is completed, then process design begins
All product life cycle stages are considered in design	Not all product life cycle stages are considered in design
Activities are performed at the last responsible moment	Activities are performed as soon as possible
Systematic efforts are made to reduce supply chain lead times	Separate organizations link together through the market, and take what the market offers
Learning is incorporated into project, firm, and supply chain management	Learning occurs sporadically
Stakeholder interests are aligned	Stakeholder interests are not aligned
Buffers are sized and located to perform their function of absorbing system variability	Participants build up large inventories to protect their own interests

4.1.1 Flow in construction

Notion flow have become very frequently used phrase in production context. However, unclear definition of flow has become to a problem. Meaning of apparently clear concept may vary depending on who is considering the concept. Different parties may have a fickle idea of what ´good´ production flow could mean, but what it should mean, depend significantly on the respondent, as production flow concept is not that familiar and clear in construction industry. If people talk about an concept, which may mean totally different thing for each one, effective performance would be improbable. (Sacks, 2016)

However, the issue of vague definitions does not appear only in pragmatic level. In his research, to identify factors that provides good production flow, Sacks (2016) discovered that to enhance production flow, the very first step should be the unification of different notions of term flow, as authors have been used that term flow rather vaguely in construction management literature. To overcome this flow definition problem, Sacks proposes a model of construction flow that includes three different flows which are interrelated but presented on own axes. The model is observed later in this research.

For comparison, concept flow is highly refined and more accurately defined in manufacturing industry than in construction industry. And sometimes, models from manufacturing industry are too directly adopted to construction field. This procedure may not provide relevant reflection of prevailing circumstances. One fundamental difference between these two contexts is in flow of products. In manufacturing industry, products flow through production line to fixed workstations where workers process the product and send it to downstream, whilst in construction industry, the actual product has fixed location and labor and tools flow through spaces to carry out operations to product. The notion of work could be understood in manufacturing industry as product. Therefore, the idea of flow and work flow contains whole different meaning in construction context. (Sacks, 2016)

Concept of flow is used often, especially in lean construction community, to present progression and movement of different things. Kalsaas and Bølviken (2010) claims that the term flow has been exploited rather broadly, quite same as the dictionary defines it ´continuous stream of something´, which provides not precise but rather intuitive comprehension about the term. Thus, it could be assumed that people may have varied comprehension about the term flow. If this term is widely used in a different of contexts, possible risk might be that term flow could mean a bit of everything, and on the other hand, not exactly anything.

4.1.2 Construction physics

As mentioned earlier, concept flow is strongly represented in lean construction discussions. To understand role of different flow in construction processes Bertelsen *et al.* (2006) introduced construction physics to illustrate first, all the prerequisite flows which enable construction processes to be sound, and second, how these different flows interact with each other. Inspiration for this construction physics model raised from Hopp´s and Spearman´s work on Factory Physic, which concern relation of flow, time and queuing theory for mass production processes (Bertelsen *et al.* 2007). Purpose of creating such flow oriented model in context of construction, was to locate and identify the sources/flows that have major negative influences to process such as discontinuity, productivity hindering and variation. As the source is once located, the corrective actions could be executed more effectively and monitoring could be focused. Examination is done from process perspective. Construction physics consider construction production as continuous process being fed by several streams.

This comprehension deviates from more traditional one where construction production is perceived as stack of sequential operations. (Bertelsen *et al.*, 2006)

Since nature of production in construction context varies enough compared to production in manufacturing context, mathematical models of Factory Physics should not be implemented directly. Focus should be in determination of nature of processes in construction industry. Specific features of construction production, such as one-of-a-kind products which tends to require unique production system, orientate the focus in determination of principles of project based production. (Bertelsen *et al.*, 2007)

Traditionally, construction projects are considered as linear series of operations with different connections and interdependencies as Figure 8 demonstrates. Adding the flow perspective, in how processes are considered or modelled, could provide broader understanding of project production. This revision decreases dramatically the importance of operations and highlights the nature of true process, like fire (flows are combustible material and oxygen). In this model, several flows such as materials, crews and information feed the process as each flow has its own feeders as well (Figure 9). This analogy express that, to control the process, flows that feed the process should be managed rather than the actual process, and at a time, each flow is a critical flow which determines the actual velocity of process. Problem is just that the critical flow is awkward to identify, because critical flow shifts frequently. (Bertelsen *et al.*, 2007)

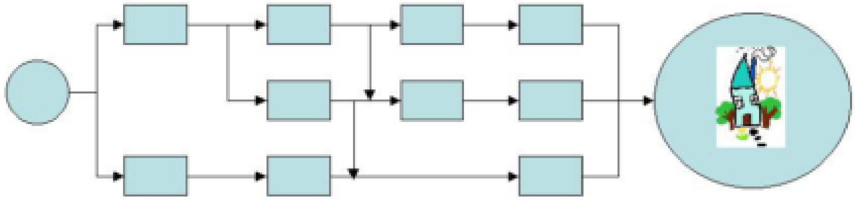

Figure 8 Production processes illustrated by Critical Path Method (Bertelsen *et al.*, 2007)

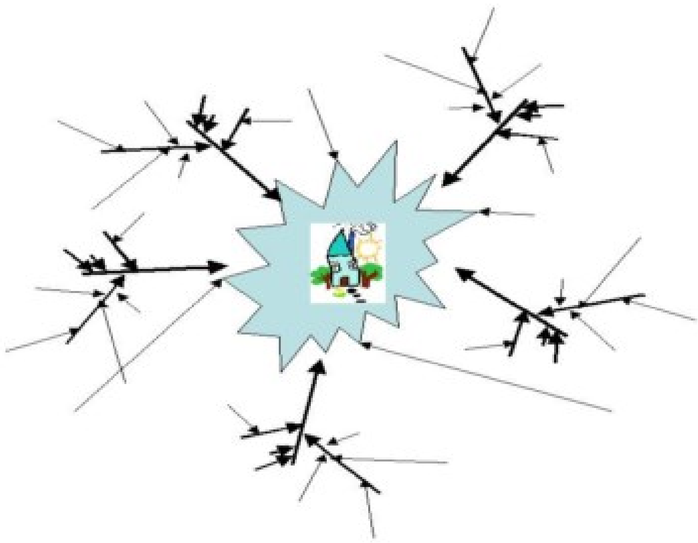

Figure 9 Production presented by True Process Model (Bertelsen *et al.*, 2007)

Production model with flow aspect provides more realistic picture of the complexity of construction production. However, Bertelsen *et al.* (2007) state, it is not obvious that this more realistic and complicated model provide relevant contribution to project managing. Nevertheless, these different models and theories provides alternative perspectives to observe and consider construction projects and production. Relevant question is not that - is one model more true than other model, for these models might focus on different factors with different emphasis. One significant contribution of construction physics' process model could be the illustration of construction production´s complex and multi-dimensional nature, with vast amount of variability. Also, the claim that too trivial attitude, comprehension or solution may generate misleading outcomes and suppositions. Above mentioned situation is apparent as Bertelsen *et al.* (2006) emphasize the importance of detecting critical flow (flow or set of flows that contains undesirable effects to process) and management orientation, basing on critical flows. But, little later Bertelsen *et al.* (2007) noted that management based on critical flows is not that obvious or relevant, because critical flow is that difficult to target. Targeting of critical flow is awkward because flows are not just independent streams - flows are usually connected to each other with influencing outcomes. Thus, reasonable seeming ideas usually do not reveal their true nature and impact to entity until piloting in practice. Also, it should be noticed that usefulness of certain practice may vary a lot depending on the environmental features, i.e. one practice may be very effective in certain environment, but totally useless in another. So, the question may be more in finding reasonable models and practices for particular environment, than finding the one and only, supreme method.

4.1.3 Construction production as a process

Koskela (2000) claims that to perform tasks smoothly on site, seven preconditions should be in order. These seven preconditions including construction design, components and materials, workers, equipment, space, connecting works and external conditions are considered as resource flows. He also demonstrated how only 5 percent uncertainty in each flow may dramatically decrease reliability of certain activity to 70 percent. Bertelsen *et al.* (2007) claims that Koskela´s calculations are rather approximate, since how uncertainty should be determined and reliability computed is not trivial. However, this model provide clear conception of potential variability in operations.

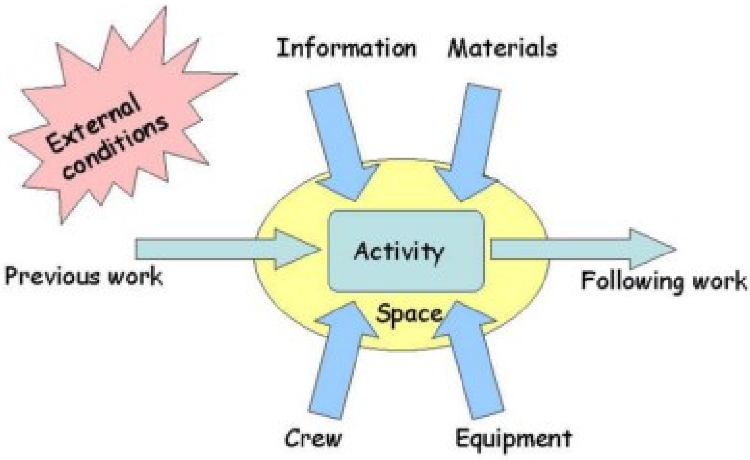

Figure 10 Koskela´s seven flows affecting the performance (Koskela, 2000; Bertelsen *et al.*, 2007)

Shortly afterwards, Ballard *et al.* (2002) introduced another construction process model with three main categories/flows representing the prerequisites for process. These three categories are directives, prerequisite work and resources. He also defined these categories. *Directives* provide guidance for production such as design criteria and specifications. *Prerequisite work* represents the ´substrate´ in which new work is added. This also includes materials and required information. Finally, r*esources* are considered as labor, tools and locations with certain conditions (Figure 11). (Ballard *et al.*, 2002)

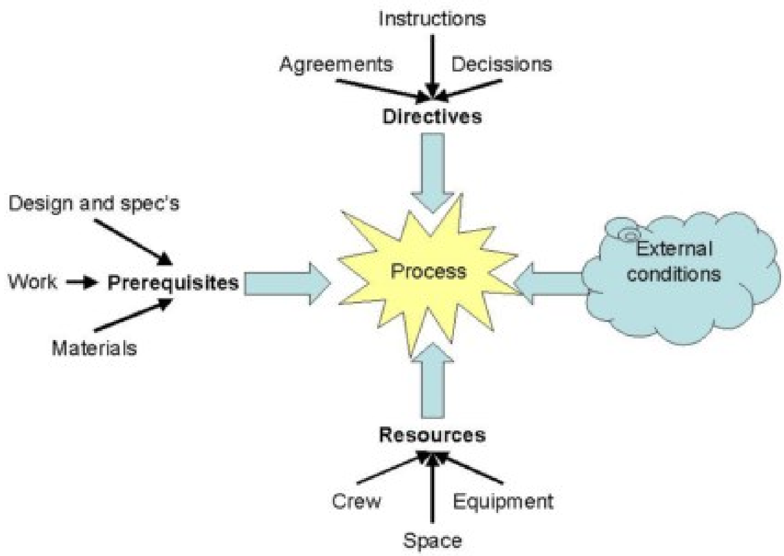

Figure 11 Process model with three primary categories: directive, prerequisites and resources (Ballard *et al.*, 2002; Bertelsen *et al.*, 2007)

These models provide more actual comprehension of processes compared to Bertelsen´s ´true process model´ in Figure 9, for these models give actual names for these different flows or features that have direct influence to processes. But then, these two models also express that things could be considered in many ways. Excluding the aspect of directives from Ballard´s model, these models contains same aspects with rather different emphasis. It is not maybe that essential to consider is one of these models more ´true´ than another or which one of these should be followed to succeed. The idea is maybe more in understanding the complex nature of construction production processes, as fixing one features at a time may not provide desired improvements. That is what Koskela (2000) demonstrated in claiming that transformation perspective, where different features are optimized separately, do not provide neither adequate comprehension nor improvements for construction production processes.

4.1.4 Even flow in construction

To control fragmented and unpredictable construction production operations, Arashpour, Wakefield and Blismas (2013) tested the functionality of even flow production principles in construction context. Intention was more to reconfigure the traditional operation system, rather than attempt to improve the present system configuration. Idea was also to measure how these manufacturing industry-based and well-tried methods by Hopp & Spearman would function in construction production. As Arashpour, Wakefield and Blismas (2013) phrase it: *"Even flow production known as workflow-levelling strategy aims to decrease variability in the workflow for trade contractors".* This kind of attention may also be found from sphere of lean construction and in this case, the actual methods to operate should be emphasized more than noble intentions. Moreover, as Sacks (2016) revealed the problematic state of concept *work flow,* for its unambiguous definition and its relation to process flow, Wakefield´s definition contains some opening for interpretation. However, without addressing these above-mentioned issues, the main idea of this implication of even flow production principles is to manage and control complex construction production with alternative approaches.

Two principles of even flow production were under testing. First principle, increasing flexibility to processes by implementing fewer, cross trained, trade crews instead of several narrow-specialized ones. In this manner, the fragmentation of labor could be decreased as there are fewer separate crews on site. Moreover, issues associated with hand-offs should also decrease for there are fewer crews on site. Second principle, constant work in process inventory (CONWIP). This means controlling the number of locations under production, at a time. (Arashpour, Wakefield and Blismas, 2013)

Equation and parameters considering WIP are introduced in Little´s law (Little, 1961) presented originally:

$$L = \lambda W,$$

where L is expected number of units in the system, W is expected time that one unite spent in system and $1/\lambda$ expected time between two consecutive arrivals to the system.

But nowadays usually formatted:

$$CT = WIP/TH$$

This equation is generally used in manufacturing context to illustrate production parameters, in which CT is cycle time, WIP is work in process and TH is throughput. Simplistically, it can be stated from this equation, that increasing of WIP extend the cycle time and therefore controlling WIP is one key factor to maintain short cycle times. Short cycle times and moderate level of WIP is assumed to be significant feature of functional production system (Sacks, 2016).

Arashpour, Wakefield and Blismas (2013) results from utilization of these two even flow production principles tend to create positive influence to construction production process, as maybe the most impressive contribution manifests in shortened cycle time/completion time of project, as presented in Table 2. Improvements are claimed to be consequences of more simple system configuration. Production improvements were enabled by faster and more predictable production system. (Arashpour, Wakefield and Blismas, 2013). These suggestions of simplifications, contain improvements to control troublesome construction production by decreasing variability. However, as complex system like is simplified, it should be very careful in where the simplifications are targeted. Removing or equalizing tricky features from production system, do not mean that they do not exist anymore. This proceeding may once again cause misleading outcomes if simplifications are not elaborated. But, properly designed and implemented, more plain construction production system may decrease variability for its part as Arashpour, Wakefield and Blismas (2013) claims.

Table 2 Table presents four different experiment projects with different strategies and measured outcomes (Arashpour, Wakefield and Blismas, 2013)

Parameters	Experiment 1	Experiment 2	Experiment 3	Experiment 4
Process time distribution	deterministic	Probabilistic	Probabilistic	Probabilistic
Production line status	Balanced	Balanced	Balanced	Balanced
System description	Best performance	Push system	CONWIP	Integrated process+ CONWIP
Raw process time (T_0)	140	alters	alters	alters
WIP_0	20	20	20	20 (jobs)
Average WIP inventory	20	39	20	19
Avg. subcontractors' time	7	20.6	13.65	7 (days)
Completion time (CT)	140	395	273	127 (days)
Job completion intervals	7	15.4	13.7	7.14 (days)
Throughput rate	0.14	0.065	0.073	0.128 (job/week)
Number of completions	124	65	111	123
Number of system states	1	$9.4 * 10^{14}$	$6.9 * 10^{10}$	10^7

Adding these even flow principles to construction context do not provide solution to complex problems per se, but rather create desirable border conditions or goals. Let´s consider situation this way, if operational strategy or production system is not functionally in order, low WIP itself would not save the situation. However, overwhelming WIP may ruin even functional production system. So, should CONWIP be considered rather as objective than procedure? Table 2 shows that system description as CONWIP (experiment 3) alone, provides better measures than worst scenario (Experiment 2). But, experiment 3 is relatively far from results of system with mixed system of CONWIP and integrated processes (Experiment 4). Direct utilization of methods from manufacturing industry should be taken with a grain, but it is the principles and ideas behind the methods that should be considered and modulated to other contexts.

In pipe renovation context, role of WIP is essential since general contractor can basically determine/choose the amount of WIP. Usually there is no restricting interdependences between apartments in pipe renovations, like in new construction, where construction of upper floor could not be started before frame of lower floor is ready. In principle, on pipe renovation site, every apartment is ready for renovation from the beginning of renovation phase, but how many apartments are taken under renovation at time should be elaborated. Potential risk lies in too fast starting pace of apartments, as amount of WIP may increase too high to handle properly.

4.2 Portfolio, process and operations (PPO) model

As abstract and implicit comprehension of production flow prevails among construction industry, Sacks (2016) investigated and analyzed existing conceptualizations of flow in both manufacturing and construction contexts, to generate one model of construction flow. Purpose of the construction flow model was to provide unite and coherent theoretical frame for construction industry. If theoretical model like this obtain broad approval, it would create common ground to comprehend and improve construction industry effectively. This relatively new model provides tentative basis for further research to create more comprehensive model of flow in construction industry (Sacks, 2016).

Sacks´ model of construction flow includes three different flows which are interdependent but still have own axis. These three flows illustrate: project flow, process flow and operations flow. None of these three flows are new concept, as they are mentioned already on literature. This synthesis model is based and influenced by flow in manufacturing, lean production, lean construction and project control in construction management literature. (Sacks, 2016)

On a large industry, it is very ambitious quest to create model which should function as common platform for how we understand construction production. Especially, as conditions, requirements and obstacles are very local and country specific. But, if suggested model is abstract enough for modification, it could be possible to modify it to responds local environmental requirements. To understand better the configuration of this PPO model the influencing factors are introduced briefly on next.

Concept work flow is comprehended and used by authors and practitioners in two different meaning. In first, work is considered as task, and in second, work is considered as product. Relevant distinction is to consider work flow as two different flows. Location flow presents the process and trade flow operations. (Sacks, 2016)

4.2.1 Process flow and operations flow

To understand principles of production Shingo and Dillon (1989) highlight two major notions – *process* and *operations,* which constitute the production. In this model, production is comprehended in a manner where process illustrates the transformation of material into a product and the transformation is executed by compilation of operations. More precise, process axis projects the flow of material through time and space, all the way to a finished end product, whereas operation axis projects the flow of tools and workers through time and space. Figure 12 demonstrates the connection and flows of these two concepts. In analyzing a process, the focus is in material/product and progress of it, whilst operation analysis focuses in actual operations of workers and machines targeted to a product. The purpose of this distinction, rises from the need of fundamental improvement of production process. To enable this development, these two flows should be investigated separately. However, improving of single operation does not improve the process flow efficiency automatically, which could be assumed trivially. In fact, if potential affects and consequences of modified operation are not precisely considered, these hasty made improvements may even harm the overall efficiency of process. (Shingo and Dillon, 1989)

These principles are designed and addressed to a context of manufacturing industry, so direct implementation may not constitute desired outcomes on construction context. Therefore, Shingo´s model of production is refined and modulated to respond the demands construction industry.

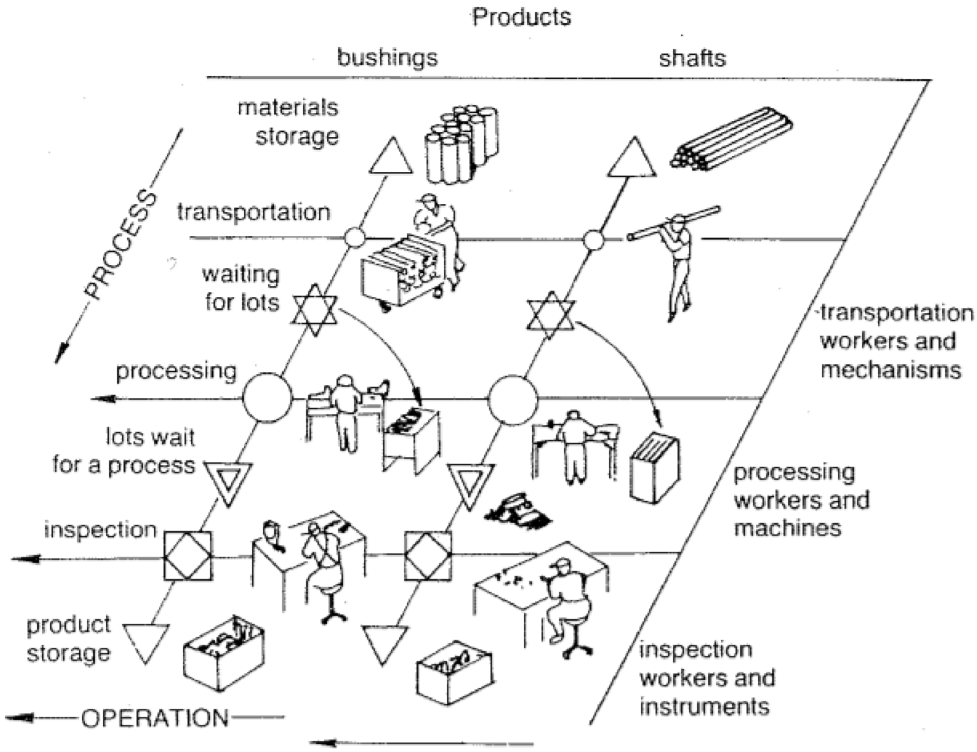

Figure 12 Structure of production in process & operation perspective (Shingo and Dillon, 1989)

4.2.2 Location as product

As process flow could be understood to consider the movement of the forthcoming product through product line and different operations, the ideological contradiction emerges as in construction industry the actual products are static and does not flow through processes. The processes rather flow through products as materials and parts are processed and assembled at the location, which can be assumed to be a certain room of apartment.

Sacks (2016) claims that in lean construction ideology, the entire project is considered as object without any subclasses such as locations or spaces of building which could be considered as distinct physical products. That may leave the object under investigation quite broad and abstract, if improvements are intended to achieve. To reduce waste, as it is one major themes of lean construction (Koskela, 2000), waste should first be located. If the object is too large, the forms of waste may appear relatively different compared the situation where object is divided to smaller segments. Other possible scenario would be the situation where the waste or problem is diagnosed only in a broader, theoretical level. The capability to help operational level may be meager for the lack of understanding the smaller, more pragmatic picture. As earlier mentioned, the low productivity may reveal itself quite differently from perspective of separate actors.

Kenley and Seppänen (2009a) suggested location-based scheduling, where idea is to set focus on tasks which expressly flow through production units, expressed as *locations* in this context. Notion task in turn is considered to present compilation of activities that are frequently accomplished in several locations of one project. So, at this level the concept of task has left quite open and ambiguous, but idea of location as a construction product is well demonstrated. Kenley and Seppänen (2009a) presents that in location production, emphasis is in the certain location and involved work. To separate project/building to distinct locations, there are several ways to execute the actual division as Figure 13 and Figure 14 introduces a typical location breakdown structure (LBS). Problems with rigid division emerges as tasks are considered. For some trades, single room may present relevant unit/location, but for some other task, vertical duct through building is the object for operating and thus, considering location as a product demands elaboration (Sacks, 2016). This remark exposes that even location breakdown is not trivial or unambiguous. Whatever segmentation is, to succeed in pipe renovation production, the segmentation should be commonly accepted among different parties. Otherwise there is a risk of misunderstandings if certain location segmentation is appreciated differently. Classic example on pipe renovation context is the ambiguity meaning of ´line´. For some groups, it might mean apartments on top of each other, and for other groups lines are building service system ducts.

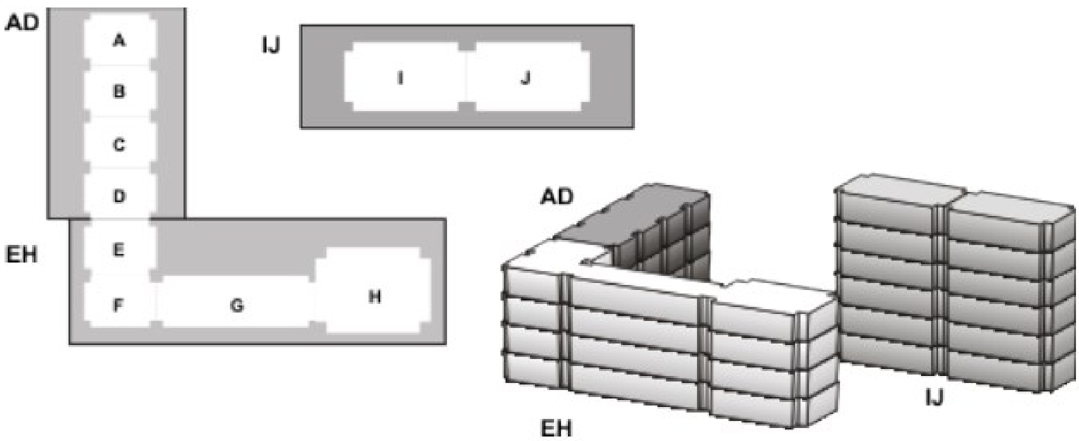

Figure 13 Typical location layout of project (Kenley and Seppänen, 2009b)

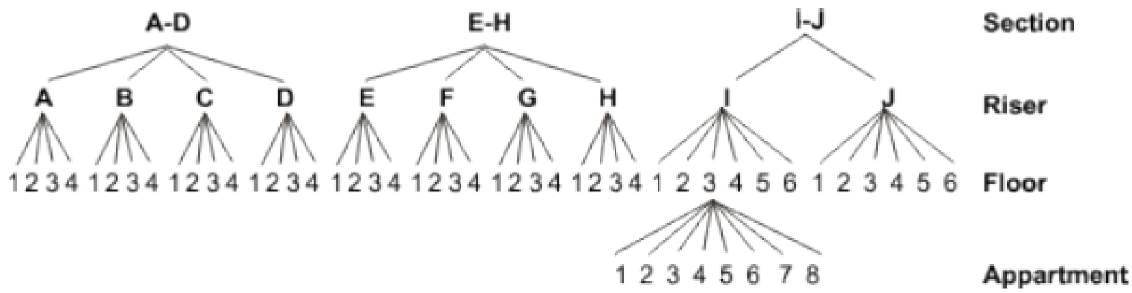

Figure 14 Location breakdown of location layout above (Kenley and Seppänen, 2009b)

It would be erroneous to presume that there is only one true model or theory to comprehend phenomenon on construction industry, or any other industry. Different faculties and paradigms regards and emphasize different factors, as main principle on one theory may be even neglected on other theory. However, significance of locations in construction production could be validated, since production of building almost never realizes as continuous recurrent process, but rather from different physical locations which comprise different requirements, work and materials (Kenley and Seppänen, 2009a). This perspective only confirms the complex nature of construction production. Although different locations may have only slight variance on demands, it is incorrect to assume directly that these locations are just two copies of each other, although it may misleadingly seem like that from far. But, if the variance in demands lies on very critical task, the eventual difference between these two locations might be remarkable. In this context critical task is comprehended as a task in certain location which prevent successors to execute other tasks before critical task is accomplished. Kenley and Seppänen (2009a) claim that key factor to success with location based strategy, is in gathering relevant data and generating substantial information for each location. Therefore, reliance on rough assumptions may lead to a very common situation in pipe renovations, where the strategy to cope is nothing but improvisation. Usually this method eventually overcome the issues but it is everything but effective.

Other inherent attribute of considering location as a product, is possibility to simultaneously perform several operation in one location (Sacks, 2016). This method is mentioned in literature as ´crowding of labor´ and ´stacking of trades´ and its probable consequences are assumed to cause disorder, as workspace diminish (McDonald and Zack, 2004, p. 4). However, implementation of this method should be considered as location-specific. For some phases of production or locations, this method is inappropriate. But, in certain circumstances, there is no any relevant reasons why not more than one tasks could be operated at the same time. For example, if location is spacious enough and tasks have no prominent interdependencies. Also, to gain positive outcomes from simultaneous operating in one location, operating should be considered and planned beforehand. Usually, crowding of labor seems to emerge as project is running out of time. Therefore, the simultaneous operating may not be controlled and positive outcomes would not be achieved.

Kenley and Seppänen (2009b) validate and emphasis location to be metaphor for product on construction industry that flows through production operations. Still, Sacks (2016) remarks that Kenley´s flow of locations model do not take a stand on defining good workflow, rather than roughly, and in Kenley´s list of characteristics of bad work flow, operation and process aspects are mixed together. That notion is in direct contradiction with Shingo and Dillon (1989) claim, that to improve production, operation and process flow should be distinct from each other.

4.2.3 Project flow, location flow and trade flow

Inaccurate definitions of terms regarding flow have set the discussion to a point where same notion may decisively mean different thing between people. Term construction work flow is genuine example of that, since different authors, as well as, practitioners have used this term to refer to two distinct flows. First, work flow is used to reflect tasks and second, work flow is used to reflect products. So, separation of work flow to two independent axes, to represent flow of operations and flow of process, would be valuable to enhance clarity of the concept. Proper term in construction industry to presents operations is *trade flow*. Process should be presented via *location flow,* introduced by Koskela (2000). This separation restrains the misleading understanding, that ambiguous notion work flow could cause. (Sacks, 2016)

This separation is practically the same as in Shingo´s description of production in which operations and processes are inspected as two different flows. These already known concepts are just translated to respond situation better in construction context (process – location and operation – trade). Anyhow, as new accurate definitions with new names are determined, there should not be room for alternate interpretation which may cause confusion.

Sacks (2016) PPO model contains also third portfolio axis which illustrates flow on projects. This means that flow of trade crews is not restricted to happen only from location to location on certain project, but also from project to project. Need to observe production on project level partially is due to high utilization of subcontractors. Subcontractors are independent firms or actors which usually tend to have several projects under way simultaneously, and therefore different project may share connection, wanted or not (Bertelsen and Sacks, 2007). Sacks also (2016) demonstrates significant feature in construction industry, as projects in certain economic region most probably share same designers and subcontract companies. For that reason, understanding the rules among different projects could help to comprehend flow of trades better. In Figure 15 (b) model of construction flow is illustrated as a three-dimensional plot. For clarity, Figure 15 (a) presents the situation of one project implementing more common line-of-balance chart.

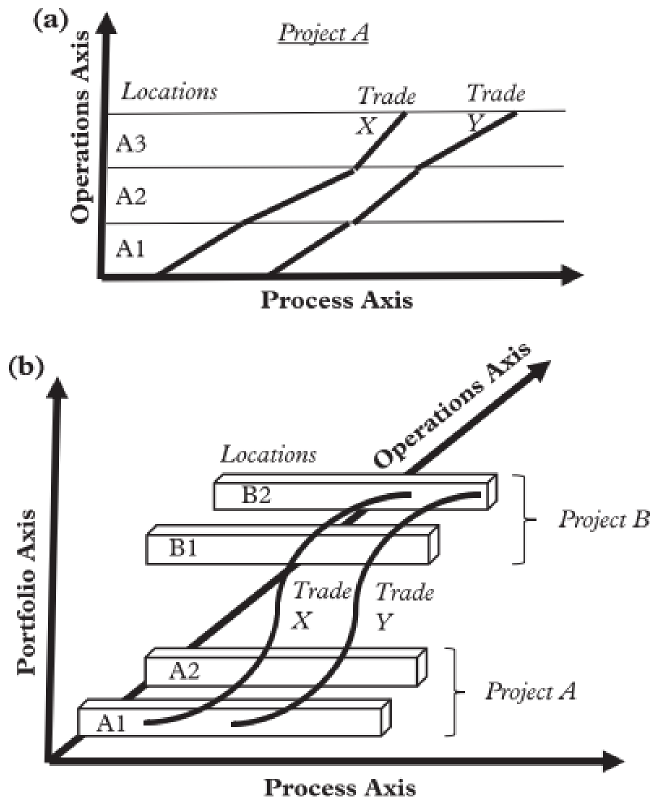

Figure 15 (a) Two- dimensional process and operation chart of single project; (b) demonstrates model of construction flow in three-dimensional PPO chart (Sacks, 2016)

As subcontractors are involved simultaneously on more than one project, they need to allocate and balance recourses to each one of them. It could be assumed that subcontractors have a strong intent to ensure continuous utilization of its crews. That may require movement of crews from one project to another. This procedure creates the flow of work force between construction projects. Hereby, the continuous trade flow disrupts the location flow of one project. Figure 16 illustrates the situation, in which buffers on Project A are supplemented on tasks from Project B to provide continuous trade flow for subcontractors trade crew. (Sacks, 2016)

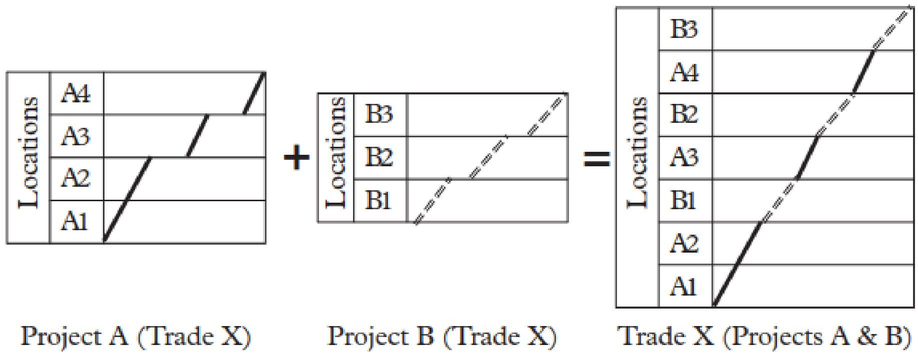

Figure 16 Continuous trade flow of Trade X on two projects prevents the continuous location flow in one project (Sacks, 2016)

For the subcontractors' tendency to shift labor between ongoing projects, the general contractor's operational strategy arises in significant role. To ensure continuous location flow, general contractors should try to plan a task schedule where breaks between one trade crew´s tasks are not long enough to awoke subcontractor's interest to shift its crew to another project. However, this planning requires also elaboration to balance location flow and trade flow.

Observing only one project at a time, and neglecting the possible influences of project level, may provide misleading picture of factors that may have impact to one project. Simplification of model may help uninitiated ones to get a hint about larger lines of construction projects, but simplified model might not take account all significant factors. Thus, utilization of narrow-minded models as decision making tools may lead to unpleasant surprises and outcomes. Sacks (2016) claims that linear hierarchy supply chain model has begun to be rather outdated in construction, for its project centered perspective where assumption is that resources are dedicated for one project, thought currently the relationship structure has more cyclical nature (Figure 17). Model of cyclical interdependencies represents the idea of continuum. Single project does not only begin and end in vacuum, but there could be continuous interaction between other projects. Usually general contractors have several projects in progress at same time and cyclical comprehension could enable better collaboration between different projects in terms of labor and information.

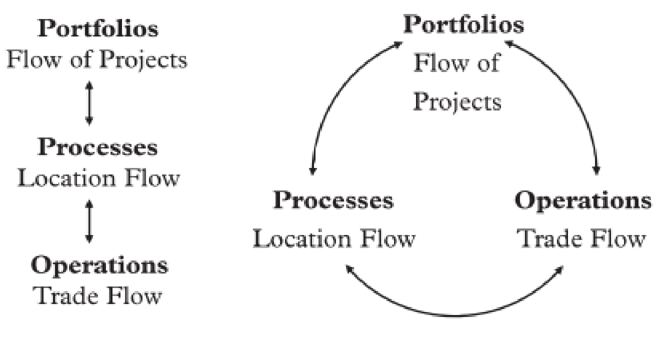

Figure 17 Hierarchical vs. cyclical nature of PPO relationships (Sacks, 2016)

In addition to these charts, Sacks (2016) has gathered complementary table of aspects to demonstrate more specifically the prevailing factors from perspective of different PPO axes, that arise on construction projects (Table 3). From table, the notion considering tactical approaches illustrates the contradiction between work manager´s and subcontractor´s intention to enable continuous flow of their interests. Work manager is interested in flow of locations, as is advantageous for him to build excessive capacity of work force, to ensure that there is always labor for open tasks. Whereas, trade crew leader intention is to wait till there is enough buffer in locations to begin operating, to ensure solid and continuous flow of tasks. As long as these two parties do not share enough same interests, the balancing between location flow and trade flow may continue.

Considering this research, standardized operations are mentioned in planning and controlling tools of operations. Although that tool is under column of subcontractor. In this research, the intention is to survey what kind of contribution general contractor could to bring in, by standardizing the operations, that are required from subcontractors. Would that blur the interface between these two actors and increase collaboration, since Sacks (2016) states that there is demand for tools helping subcontractors to allocate their resources.

Table 3 Aspects of the PPO axes in construction (Sacks, 2016)

Aspect	Portfolio axis	Process axis	Operations axis
Flow object	Project/building	Location	Trade crew
Cycle time for flow of a single object	Full project duration	Start of structural work to delivery to client	From first to last day of a crew's work on a project
Optimization targets	Project duration and cost	Flow of locations, reduction of WIP, minimum cycle times, quality	Flow of trade crews in and between locations, continuous work, productivity, safety
Management function	Project manager	Works manager or superintendent	Subcontractor, trade crew leader
Planning and control tools	Critical path method (CPM); contracts	Location-based planning; Last Planner® System (LPS)	Operator balance charts; standardized operations; LPS
Symptom/ sign of waste	Budget overrun and/or schedule overrun identified using 'Earned Value' measures; defects	Unoccupied spaces (spaces with no work in progress); crews absent from site; delayed materials; delayed design information; rework	Idle crews on-site; crews waiting for work; small work completion packages; rework
Tactical approach	Contract negotiations, bonuses and fines	Build excess capacity; coordinate across trades	Allow buffers of locations to accumulate before assigning resources, understaffing
Scope of planning and control	Single project	Work or product type (e.g. structure, building systems, interior finishes)	Operations (specialized trade work)

4.2.4 Principles for good production flow

As different flows of PPO model are determined and observed, it is relevant to examine method to achieve good production flow. Sacks (2016) highlights two main themes including first, all three flows should be on good level, to obtain desirable overall construction flow which in turn requires collaboration of different stakeholders and second, focus should be especially on flow of locations, for it seals in the greatest potential for improvements, since in traditional practice this aspect is usually neglected. Sacks (2016) also demonstrates that improving of location flow have major positive influence to other two flows.

To improve construction flow, it is not possible just first fix task flow, then location flow and finally project flow, since these flows are not independent or static (Bertelsen and Sacks, 2007). So, once fixed flow does not explicitly maintain the reached state, for it is constantly under influence of other flows and factors. Improving of construction flow seems to involve such iterative characteristics. Eventual, broader outcomes are difficult to predict absolutely. Some improvement may seem to work out fine in the first place, but later, some previously absent problems may start to occur. Sacks (2016) claims that many senseless decision, harming process flow, are risen from attempt for local optimization with narrow point of view. Due to the complex nature of production in construction, mental attitude for improvements would rather be experimental and iterative – let's try this, then elaborate the results, then refine it and try it again, – than absolute – this will work, without a doubt.

Sacks (2016) finally states that there are not certain specific tools or methods to improve location flow, as question is more about understanding the principles behind these methods. Tools do not create strategy but tools may help to implement the strategy i.e. completely poor strategy might not be saved by fabulous tools.

Overall, PPO model may provide fresh summarization of production flow in construction. Model provide also basis for further exploration of new methods and theories. The scope of this model reach from task level to multi project level, which reveal the flow of labor over one project. However, Sacks (2016) remarks the limitation of the model, for it does not explicitly regard three eminent flows of materials, resources and information, which contribution for production are unquestionable.

4.3 People, process and information

As PPO model emphasized the importance of three different flows to understand production in construction project, Dave *et al.* (2008) impress the importance of people, process and information to achieve innovative and effective manners in construction industry to guarantee the stable future. Due to the close interdependence of these three factors, the improvement actions should be focused simultaneously to each one of them to avoid the unwanted and hindering outcomes (Dave *et al.*, 2008). Idea is to avoid sub optimization of only one feature and assumption of other features should evolve simultaneously on the side.

Rising people and information beside to the process would be relevant approach to explore the performance in construction production, for its characteristic features such as labor intensive work and unique plans. Deeper understanding of these features may provide useful perspective in quest to improve productivity of production. Neglecting the importance of information distribution and human nature, may cause lack of prospects to understand how these features may act in practice.

Dave *et al.* (2008) depict production in construction by physical processes which are described and supported by information. This model contains all three aspects including process, people and information. Although, even this model is not all-inclusive, it provides valuable remarks whose relevance could hardly be denied in improving performance on site. Plan updating and almost constantly changing situations demands effective information system on site to provide smoothly progressive performing. Without functional information system, underlying risk is that different actors on site perform with outdated information or plans (Alshawi and Ingirige, 2003). Often this causes rework and waste.

Problems rising from communication of people and harming the production are discussed in Vrijhoef and Koskela, (2000) research. These issues are related in how different actors are able to share information to each other’s – how issues are presented and how issues are understood. Often communication between people is not unambiguous. It is not uncommon that different actors misunderstand each other’s on site and correctly planned operations failure, because of the communicational shortages. For these kinds of reasons as well, emphasizing the role of people and information should be validated.

Role of information system has also impact to performance of people. Poorly designed and implemented information system may rather disempower actors than enable them to perform more effectively (Dave *et al.*, 2008). This may refer to a question of how information is stored and distributed in one project. In some cases, valuable and detailed information may have been gathered, but complex storage system may prevent the effective utilization of information. Thus, information does exist but is awkwardly available. Utilization of ITC technology should emerge at this stage. However, the situation is not so obvious that the ITC tools would be direct answer to information and communication problems. Dave *et al.* (2008) mention two major factors concerning the utilization of ITC technology first, if the production system is fundamentally chaotic in the first place, incorporation of ICT tools does not facilitate the situation but vice versa, it would make it even worse, and second, it is the principles and needs that determine the way of using ITC tools, not the latest version of ITC tools. So, tools in any case should be aiding the process, not determining the boundaries for it or making it more complex.

Other problems concerning the storage and distribution of information is phrased as islands of information, in which information is stored on different platforms (Dave *et al.*, 2008). In this case, some needed information might already be stored somewhere, but if it is stored on different software system, utilization of that system may be difficult. Thus, different actors acquire already existing information by their own manners (depending on case, either easy or hard way), and unintentionally hide it from others. And as another actor needs the same data, he probably goes look for it in the manner best observed and so on. This procedure most likely works and same factor would become assured several times, but this procedure is very inefficient because of rework. On construction site, this procedure of many times acquired information is quite widely used.

Kauppila (2014 p. 40) claims that separate sites are performing in their own insulated ´bubbles´ and thus information sharing between projects is almost non-existent. Therefore, valuable knowledge and experience would not be utilized effectively although required information may already exist. This might partly explain remarkable differences in performance between distinct project under same construction company.

With functional information system, organization is able to gain flexibility to its performing, which is important feature in rapidly changing environment (Dave *et al.*, 2008). As situation or procedures changes, new information should be distributed between involved actors effectively and clearly to ensure the progression of process. Figure 18 suggest how these three factors could be linked to each other. It is notable, that this model is similar for its structure as Sack´s cyclical PPO model. Thus, the interaction between these factors are no hierarchal. This model illustrates the situation quite well since information do have affection to both people and process. The same applies to people and process obviously.

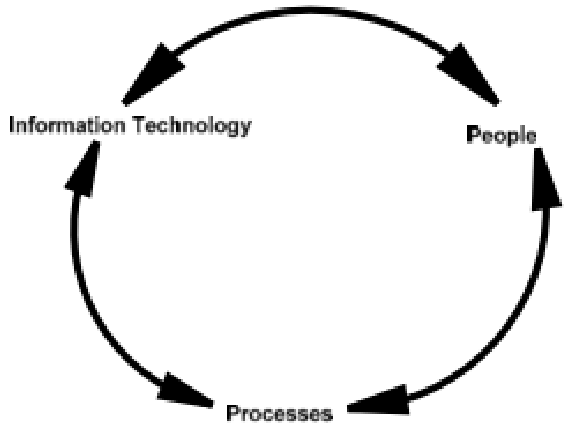

Figure 18 People, process and information technology support each other (Dave *et al.*, 2008)

Although this model does not take a stand on relatively significant factors considering production processes such as work and materials, the emphasizing of human features and information provide additional comprehension of construction production. It is notable that process ongoing and project team composition determines largely what kind of information is valuable. Other issue, in pipe renovation context, to resolve is what information is mandatory for certain actor to perform effectively. It could be assumed that every actor does not require all possible available information. Question is more about where the right information should be found. And as we are talking about human, what should be relevant format and ´language´ for information, is matter that should be elaborated.

4.4 Evaluation and summary of models

The complex nature of construction production process is clearly revealed in observed models for there are so many different factors possibly influencing the processes. As these models emphasizes and regards different factors, idea is not trying to distinguish untrue models from the right one, but elaborate how these models could complete each other and provide more comprehensive understanding of construction production. Themes of the models should also be reflected with practice to be able to determine proper weight of certain factor since environment may determine the importance of one factor for its part. Next intention is briefly raise relevant main points from the models previously investigated.

The purpose of production is to generate products. In construction, product is building which consists of several rooms/spaces. Thus, Kenley and Seppänen (2009) suggestion of location as product would provide reasonable procedure to consider the situation. In this case, operations could be targeted to specific locations, which provide more precise information for management and labor. Often only amount of work is somehow determined, but that only gives answer to *how* much, not *where.* Therefore Kenley and Seppänen (2009) proposal of principle where important location specific data is gathered and processed may provide valuable information that could positively influence site performance. However, what is valuable information concerning pipe renovation production? That question should be solved in empirical phase of the research. On the other hand, the distribution of information creates its own questions too. How the information is shared in practice between different actors in site? Answer to that question is not that obvious yet. At least it can be said that information system should be functional (Dave *et al.*, 2008), but how the distribution is actually accomplished requires more practical consideration also.

Distinction of operations and processes flows in Sacks (2016) PPO model provides understanding in how these two elements should be considered separately, especially in consideration of improvements. Although operations would be accomplished effectively, it does not automatically mean that progression of processes is effective too. So, the perspective of product and installer may vary significantly, as efficiency is considered. Understanding that provides more profound comprehension of how different groups, such as general contractor and trade crews might experience the situations on site. Potential threat for smooth production flow could be the situation where different parties just try to optimize their own performance and disregard the entity and other actors.

But what are the processes and task? PPO model demonstrates how these two notion could be comprehended, but in empirical phase relevant operation solutions and tasks should be detected and determined.

Highlighting and noticing the meaning of other simultaneous projects to one project is substantial in practice as generally same subcontractors act on certain region. Due to this, events on one site may have affection to other sites (without capability to do anything about it). That may create more or less spontaneous changes to intended plans, and neglecting this factor would be rather foolish. On the other hand, this connection of projects provides also option for collaboration over projects. If prospects of operating between certain groups are prolific, collaboration could be refined and improved. If partnership could last longer than just one project, common ways to act and communicate could be enhanced more effectively.

Inspected models also proposed several features and border conditions which should enable effective performing. In addition to some quite abstract and appealing features such as healthy collaboration, reliance and respect between operating actors and endless will to learn more, WIP seems to be something that should be payed attention. Vast amount of WIP may increase cycle times as well as it complicates control of system (Modig and Åhlström, 2013). It should be considered, what amount of WIP at a time would be reasonable for project management as well as subcontractors to handle. Risk would lie in it, if too many open tasks/locations ruin functional production system, as the capacity to operate is exceeded. In that case, resources of project may not be enough to perform effectively.

Table 4 presents the clarified key issues of research so far as well as open issues that should be observed in empirical part of this research. Theoretical inspection has provided certain frame and perspective to observe the situation under research as well as basis and structure for constructed model. However, still more substance and practical understanding is required to be apply the theoretical features. In next chapter, intention is to observe the situation in practice and clarify still open questions presented in Table 4.

Table 4 Summary of features and challenges of construction as well as suggested production models: current research and open questions

Current research	Open questions
Complex production with lot of variability. Several features causing variability to processes interferes steady production	What is valuable information concerning pipe renovation production?
Project level comprehension. The design of constructed model should be generic i.e. possible utilization in all projects	How information should be distributed in practice?
Focus in processes and locations. Constructed model should be location/process oriented to enable more potential improvements to production	What kind of problems occur in practice?
Solutions should be standardized to decrease variability in processes	How issues manifest in pipe renovation site?
Significant role of information management in labor intensive production	What are the workable solutions to utilize and what are involved tasks?

After theoretical inspection, intention is to move on to concern the topic with empirical methods. In this manner, it is also possible to examine how the theory reflects to practical issues.

5 Pipe renovation in practice

In the previous chapter, theoretical aspects of production and processes were observed to gain understanding how these issues are comprehended in literature. In this chapter understanding is gained by exploring the issues and situations from pragmatic point of view. Intention is also survey how the theoretical aspects match with the practical world. Other main objective is to seek and identify the functional solutions on which the constructed model is based on.

5.1 Introduction of target company

This research is implemented with target company Fira Palvelut Oy which is focused on pipe renovation projects. Fira Palvelut is established in 2010 and it is part of Fira Group Oy. One main agenda of Fira is to improve utilization of digitalization at construction field. Fira has also created a strong service orientated corporate culture. One main agenda of Fira Palvelut is to bring service oriented view to pipe renovation field. Therefore, customers are provided to take part to the project if they desire, with variable range of participation from higher level of participation to no participation at all. This protocol enables great opportunities for collaboration during projects but however, also creates certain challenges to resolve. For instance, a significant chance for variability to operations if desires/demands of customers shift a lot from another.

Main target projects for Fira Palvelut are pipe renovations of apartment houses, constructed between 1950 – 1970. Fira Palvelut acts as general contractor and work is implemented by subcontractors in pipe renovation projects. Thus, Fira Plavelut utilizes its own site management but not own construction workers. Therefore, collaboration of general contractor and subcontractors is in significant role in Fira Palvelut´s pipe renovation projects.

5.2 Methods

In this research, data is gathered from four different projects of Fira Palvelut. In this context data is considered as typical offsets, problems and practices on site. Buildings under pipe renovation projects were constructed between 1955 – 1961 and therefore these four projects are representative sample for research. Two source projects are recently completed, third is currently in progress and fourth is about to begin.

First step is to familiarize with the plans of projects to get the comprehension of which kind of basis the production is founded on. After that, it is possible to inspect how well the plans reflect the real situation. This mean the level of feasibility. Is it possible to implement the plans reliably or does the plans include lot of contradictions and confusing features? Are locations executed as planned or is there constant need for application and re-design?

In projects I-III, main source to investigate deviations and problems are documents made by site management. These documented problems are also divided in different categories to perceive the distribution of occurring issues. In project II, observations were also made at the site during renovation phase. Progression of work is also monitored in project IV on the spot. Because of the short schedule of the research, it is reasonable to utilize projects in different phases to gain more data and information - from preparation phase to final results - as usually turnaround of one project may take more time than this research altogether.

5.3 Solutions from the perspective of plans

In pipe renovation project, plans concerning building service systems including water, sewer, ventilation and electricity are in major role. These plans demonstrate where new building service systems are intended to locate. Plans concerning structures are usually in minor role since operations in pipe renovation projects seldom interferes to loadbearing structures on the scale, that loadbearing capacities of structures should be considered. However, possible situations, where structural designs could be required, are bigger perforations of loadbearing structures, widening of doorways and demolition of load bearing intermediate floor. In this section, building service system plans are mainly under investigation, since these plans have biggest influence to operation planning.

In general, it could be considered that these investigated plans provide quite overall-view about where the new building service systems should be located. This overall oriented planning could be explained by imperfect preliminary information. Traditionally, every apartment under planning could not be visited on the spot. Thus, the plans may not reflect the true state of apartment. Enlightened assumptions and original plans are the basis of planning. But as practice shows, fifty-years old original plans may contain huge variability in reliance. It is not obvious that every detail is accomplished decades ago as these original plans suggest. Typical issues considering old plans and old, mainly hand-made production, occur in case of ducts. For instance, new plans may display that certain duct is straight and locates in kitchen. In reality, this particular duct may be everything but straight (make curves along the vertical way), blocked for some part of it or does not even exist (quite rare but not impossible). Moreover, it is possible that over time residents of apartments may have carried out their own renovations, which in the worst case are not documented anywhere and therefore, new plans may not regard these modifications at all.

Due to this possible shifting between plans and reality, plans should be considered with certain level of criticality. If operations are determined directly per plans, several issues are faced with very high probability. Practice, as well as this research, have shown that to guarantee reasonable operating, information plans should be questioned. Not only for sometimes plans are directly impracticable or contradictory, but plans do not always provide the ´best´ or more workable solution for certain operation for certain location. Sometimes plans rather provide just one, not that optimized, suggestion to operate. That is reason why it is relevant to inspect these plans (project I-V) collectively rather than separately.

Reliance on plans is crucial for efficient production in pipe renovations. For example, in source project IV, installation and utilization of one vertical service water line was so impracticable that it had to be removed from the plans and replace it with another solution. If similar unpleasant surprises, occur frequently and unexpectedly, production could be interfered massively. Considering the production as entity, variability in key factor, like vertical water lines, do not have influence only to its own installation works but other works too that depends on vertical water line. Thus, shifting of one key factor may induce huge reorganization of operations, if the factor has critical nature in production process i.e. interdependence with several operations.

However, it would be incorrect to claim that these investigated plans were totally useless. More relevant description for these plans would be the notion that they present broader, not that detailed depiction of forthcoming measures. If production system and tasks are planned on very detail level exclusively by initial plans, problems could hardly be avoided. More detailed planning of operations should be based additionally on some other information sources too. Generating that source is one major key objective of this research. Initial plans demonstrate quite obstructively where new building service systems are intended to locate and what kind of features there might be, but how the actual work is planned and executed is other question.

As this idea or attitude towards initial plans is adapted, the relevance of investigating how many times the initial plans did, or did not, hold the true in every detail, is not that reasonable anymore. It is more about how reliable the larger lines are, to provide the principles of production. More specifically explained, the initial plans demonstrate practically how new building service systems are imported to apartments, but what comes to the routes and solutions on apartment level, initial plans tend to provide only solutions for ideal case. And if the premise of certain apartment varies from ideal, the solutions for operating should be reconsidered.

In context of pipe renovation, essential question is not - could certain solution be executed or not? Question is more about - is certain solution practically reasonable, effective to operate and satisfying for its results. Poor solutions could be executed, but that might decrease productivity of labor and quality for customer. Intention should be in determining reasonable solution for each location. Problems emerge as one solution is forcibly utilized in several locations with varying offsets. So, the problem is not always poor solution but the implementation of one solution in disadvantageous environment. This situation is intended to fix with standardized solutions.

Other significant factors considering the implementation of standardized solutions are - how and when information should optimally be gathered from locations to determine right solution. Those questions do not lie within the borders of this research but those factors may have significant value for utilization of this model under generation.

5.4 Solutions from the perspective of site operations

In this section, every source projects are briefly introduced and investigated. After inspection, occurred issues are compared and analyzed to obtain comprehension of nature and prevalence of problems – does these problems emerge frequently and from project to project or only seldom and in specific circumstances. However, due to dynamic nature of construction production, possibility to locate and document every single issue, delay and interruption would not be realistic at the moment. Thus, the results from site investigations should not be considered as all-embracing survey of production problems, but rather as survey of issues that could have been detected and documented.

5.4.1 Project I

This project is already completed. Project was quite small with 19 apartments, but schedule of project was however remarkably tight. Exploration of this project is carried out by inspecting the logbook that site manager kept during renovation phase. It is not usual to get this comprehensive diary about issues of construction site. Generally, issues are rather handled with improvisational manners without any documentation or inform to other actors or supervisors. Usually announcement to others are done if problem could not be fixed immediately. These procedures complicate monitoring of errors, since many issues remains only to certain people awareness. Thus, it is hard to accurately determine how many times certain problem truly occur in one project.

Documented deviations of project I emerged on quite wide range. These deviations are divided in 14 different categories and numbered by appearance of issues in Table 5. As Table 5 shows most of the deviations concerned logistics, site´s courses of action, incomplete tasks, planning of operations and materials. Typical issues also emerged such as fragile condition of existing ducts, need to reconsider routes of sewer pipes and inefficient communication system (how to reach necessary actors).

Table 5 Deviations and problems of project I

Category	number
Logistics	7
Site´s courses of action	11
Communication	2
Features of old building	4
Residents´ own renovations	2
Inoperable tools	3
incomplete tasks	10
Planning of operations	20
Routings	2
Materials	8
labor resources	3
customer´s changes	2

Notable issues concerning planning of operations was that the requisite information was missing to design workable operation plans. Documented issues were phrased such as "installers need more detailed task descriptions", "tasks should be determined for apartments" and "routes for sewer and water pipes should be considered better". Some of incomplete task are consequences of inadequate information as only half are known. Simplified example could be situation where plumber know that sewer pipe should be routed to a kitchen. But, what he is not so sure about is where sink accurately locates and is there some limiting features concerning the horizontal route of sewer pipe. Without better information, plumber deduce the location of sink and assume that there are no obstacles on a route and complete the task effectively and move on to another task. With good luck plumber´s assumptions turn out be right and harms such as rework are avoided. Unfortunately, this is not always the case and rework is required to fix the sewer route.

Issues concerning site´s courses of action reflect somehow unorganized performing. According to documented notions, it seems that operations are not defined or unified. Therefore, how certain operation is accomplished is rather in the author´s hands. Also, remits of different actors were not determined or shared clearly. In these circumstances, quality of performance depends majorly on actor's expertise and know-how. This kind of operating is not absolutely doomed to failure but it is very badly scalable. Reactive operating is hard to standardize.

5.4.2 Project II

The second source project is also completed. This project contained three apartment houses with 80 apartments and schedule was relatively tight. Some documentations concerning deviations and problems of this project also exits (recorded by site management), but not as detailed as in project I. Progression of this project were also tracked on the spot during renovation phase.

Notable main issues of this project were huge amount of undetermined work, large WIP inventory and variability in operations and materials. These factors are likely to make controlling of project burdensome. Structure of operating was not either that organized. Many procedures, to overcome obstacles, were created in situ as problems emerged.

Valuable, location specific information was not either gathered beforehand as much as it would have been possible. Gathering of information was not usually initiated until the need for information was noticed. Therefore, lot of time were consumed by information searching during renovation phase. That time was taken off from managing and decision making. Also, vast amount of accumulated information was silent data, as it was mainly documented only in certain actors´ heads and notes. Information did not flow efficiently between people involved. In this case, the absence of necessary actor could create void of information that might complicate decision-making since requisite information is not available as needed.

By investigating building service plans, it can be noted that some building service routes from original plans were also modified. Horizontal main line of waterpipes in one building's basement required totally new route for lack of space in planned route. Also, some horizontal routes required little modification in apartments. However, the situation with routes in apartments were somehow eased by the fact that apartments on top of another, were generally copies of each other. Thus, as the new workable operation solution was concluded, it was relatively easy to copy from apartment to apartment.

Some problems were caused by individual features of apartments. As more detailed examples, certain location of exhaust valve or order of household appliances in kitchen required some specific measures. Typical issues with location of exhaust valve emerged if valve was on the way of new electricity routes or new ceiling. In latter case the vale should be relocated either under or to the ceiling. Recurring issues with horizontal routing of sewer pipe in kitchen was the situation, where between vertical sewer line and sink, there was heavy household appliance such as oven, dishwasher or refrigerator with no ground clearance. In these cases, sewer pipe´s horizontal route could not be in lower plinth of kitchen cabinets, but the route should be drilled in the floor, under the appliances. These methods are examples of solutions that are considered to be standardized for wider use.

Most typical issues, concerning condition and space of old ducts, could not be avoided neither in this project. Several existing ducts, which were intended to utilize for vertical sewer lines, were too tight for accomplish installing works of sewer pipe and fire seals as planned. Inadequate cross-section of ducts forced management to find out the measures which would enable the installation works reasonably. The invented method demanded collaboration of different subcontractors to succeed. Also, narrow partition walls (unintentional perforations during demolition works) and exceptional structure of intermediate floors caused extra work which effects multiplied along the project. Above mentioned issues are good examples of undetermined but still existing work that have impacts to previously created schedules since there are more tasks to accomplish than originally assumed.

Distribution of documented deviations and problems in project II are presented in Table 6. Considerable notion is fewer number of documented issues compared to project I. However, these observations in project II are much more comprehensive than some of project´s I observations which were quite detailed and accurate. From Table 6 it can be noticed that highest number of problems emerged also in planning of operations. Next most issues come up with communication, customer´s changes and old structures of building.

Table 6 Deviations and problems of project II

Category	number
Logistics	3
Site´s courses of action	4
Communication	5
Features of old building	4
Residents´ own renovations	0
Inoperable tools	1
incomplete tasks	1
Planning of operations	13
Routings	0
Materials	0
labor resources	3
customer´s changes	5

Remarks raised from issues concerning planning of operations included notions of quality of plans made by general contractor, since they contained some contradictions and pure errors, ambiguity in operations, since different actors did not share always common comprehension about content of work and methods, and how certain tasks should be determined on certain location. Performing on site included lot of reactive features. From distribution of problems, it could be deduced that in bigger projects, meaning of communication and customer´s changes receive significant role. Unique wishes of customers generate variability to processes in larger scale. This increased variability may complicate the production. As bigger project generally requires more actors, communication gets also more complicated, since sharing of important information could not be done by one phone call anymore.

5.4.3 Project III

Third source project is still in construction phase during this research. Project contains six buildings with 91 apartments and moderate schedule. Exploration of this project is executed by inspecting reports of management and plans. Management have documented problems on quite detailed level if compared to project II.

Problems in this project was majorly concentrated on areas of technical solutions and routings (Table 7). Familiar problem in project II with sewer routing and household appliances in kitchen was also mentioned in documents. Several problems also occurred due to unique plans of customers. These unique plans caused a need to reconsider the building service routes and thus, variability to operations. However, even originally planned routes required re-design. As plans of project III were investigate, it seemed like practical feasibility of plans were not considered profoundly enough. These issues generated huge amount of planning for site management, during renovation phase.

Two possible conclusion could be deduced from the documented problems and Table 7, first the reliability of plans was erratic and second, forthcoming possible troubles was not detected or managed effectively beforehand. One thought rises, as if this common situation have caused problems in projects before, could communication and shared experiences between projects hinder occurrence of these already faced issues? However, as evidenced in the documents and likewise in project II, workable solutions were distributed to wider use inside this project, since they were found. This procedure could be somehow presumed as a preliminary stage of solution standardization. The apparent shortage still seems to be the isolated nature of project since partly same issues are faced from project to project and methods to overcome these issues are invented all over again, although workable solution might already exist.

Table 7 Deviations and problems of project III

Category	number
Logistics	0
Site´s courses of action	5
Communication	0
Features of old building	8
Residents´ own renovations	0
Inoperable tools	0
incomplete tasks	0
Planning of operations	3
Routings	13
Materials	1
labor resources	0
customer´s changes	10

Planning during renovation phase consumes lots of time and energy of managers and actors. Since, operating on site is not accomplishing the plans, but rather continuous stressful coping from trouble to trouble. In a longer run, chaotic environment like that may decrease person ability to act effectively or even reasonably. This usually causes regression of decision-making and judgement.

5.4.4 Project IV

Renovation phase of source project IV began during this research. Intention was to take nine apartments under more accurate and detailed inspection and monitor the progression of these nine apartments in real time. In this case, observations were not based majorly on reports done by management, but more on researcher's findings on field. Thus, it was possible to obtain different premise to gather data compared to other source projects.

Before the actual renovation works on field began, current plans were investigated and analyzed to constitute idea of forthcoming operations, but also to detect possible errors from plans. Then, assumption operation solutions were determined to each apartment, based on the plans, since there was no option to visit in each apartment before the renovation phase to carry out some substantial checks concerning the operation solutions.

Several contradictions and awkward procedures were detected from plans beforehand. It seemed like practicality of planned operation solutions were not every time thought through.

Moreover, even totally unfit methods/routes were proposed in the plans. Such mode of action raises the question – what would designer do if he cannot find reasonable solution to a problem. As leaving the situation open is not an option, would he rather just draw route which cannot be accomplished in practice to get the plans ´finished´. If this kind of unworkable solutions are not mentioned in plans, it is first, other stakeholders task to detect these errors, and second, find out other workable solution to overcome the issue and continue the process.

Only one of these nine apartments was possible to produce basically by plans. In other eight apartments, original plans required reconsidering. In all, eleven deviations occurred concerning original plans. The size and significance of emerged issues varied, but every issue required effort of management to be solved. These problems could roughly be split in two categories – plans that were simply impossible to carry out and unpractical plans that should have been replaced with more workable solution.

Three out of eleven deviations were impracticable. Most significant issue concerned one vertical water line. For lack of space, the horizontal routing and distribution was not possible to adapt in practice, while on paper it was. Although the alternative solution (utilizing one vertical water line for two bathrooms and one kitchen per one floor) was found relatively quick, this issue prevented operating for several hours and new solution changed content of earlier planned work. Thus, single error in significant part of plans may interfere process notably in wider perspective. Issue with household appliance on the way of sewer pipe in kitchen also occurred in one apartment, but this time problems were avoided because of early reaction. Above mentioned situation, could be considered as first deliberate and successful implementation of solution raised from previously detected problem (project II and project III) during this research.

Other seven deviation from original plans were caused by laborious and unaesthetic solutions that could be replaced by lighter solutions with fewer tasks and better aesthetic results. These situations considered mostly how new water pipes should be routed from bathroom´s ceiling to a sink. Two proposed `bulk` solutions were replaced with four lighter (considering number of different tasks) and more suitable solutions. To improve productivity, poor practices should be replaced with more effective ones. However, to approve the functionality of substitutive solutions, information provided by plans alone may not be enough. Usually more detailed and location specific information should be gained to guarantee the of functionality of new solutions.

In this project, also one issue could only be noticed after demolition works as one existing ventilation sewer pipe was in contact with wall of duct which prevented cutting of pipe with proper tool. Problem was not that massive, but it interrupted works since demolition worker did not know how to act in this situation, neither site management could not provide immediate solution. As solution for this problem was pronounced (erasing two brick behind the pipe) progression of process continued. However, that solution generated some extra work since by erasing these bricks, wall of bedroom was also pierced and that required to be handled too. This example demonstrates well, how easily need for extra work emerges in pipe renovation projects. This complicates up front allocation of resources, since amount of work may increase during operating phase. Although, occurred tasks would not be that hard or complicated, there might not be resources to execute them immediately as buffers of labor are usually avoided.

Other notable issue emerged as picture and text part of bathroom description created by general contractor contained pure contradiction. Because of this, end result was wrong and correction of situation required at least two days' rework. This example demonstrates how erroneous descriptions or plans may generate extra or rework.

5.4.5 Comparison and summary of projects

In this section, observations and insights from projects are compared and summarized. First notion considers implemented sources of data – how documents, created by site management, should be concerned. As earlier mentioned, these documents provide only one perspective to approach the case. As these documentations are carried out by humans, subjective considerations (what issue or deviation is significant enough to be documented) are evident. For example, for project II Table 8 shows no problems with routings, but on-site observations reveal that routing problems occurred. It could be assumed, that occasional problem with horizontal sewer pipe routing here and there were not worth to mention for management in project II, unlike in project III. So, number zero on certain category on table, does not directly mean that certain problem is totally absent. It is also possible that some issues are not simply detected or taken into account.

However, site management´s documents reveal something about the nature of the problems at site. In projects I and II, most problems were experienced to accumulate in field of operation planning. In short, management felt they are lacking requisite information to provide better guidance for labor. This issue is congruent with Siikanen´s (2011) claim that task level direction is the weakest segment of production management. This problem could be considered somehow as double-barreled. First, actors on site do not have enough locations specific information to determine which operations should be carried out and second, the ability to utilize different solutions is mainly based on actor's own know-how. Site manager or installer is either aware of certain possible methods to tackle obstacles, or not. If not, management of one project is forced to come up with workable solution. As emerged issues/deviations and invented solutions are very poorly documented or distributed, these cases and solutions may remain as intangible asset and silent information for certain involved actors. Not as intangible asset of company that actors present. If, let´s say, important actor someday leaves a company, he/she will sweep away all invented solutions and methods with him, and represented company might lose most of acquired knowledge. Hence, new successor should begin to scrape up these solutions for him all over again. By experience, every actor may, or may not, learn their own tricks. This leaves production rely on individuals rather than strategy or system. One company should gather and uphold emerging practical manners, then orientate its staff to utilize them. In this manner, dispersions between actors know how could be somewhat equalized and individuals should not act solely on their own knowledge.

Table 8 Documented issues from three source projects. Most present categories are highlighted with red and three next present with green.

Category	Project I	Project II	Project III
Logistics	7	3	0
Site´s courses of action	11	4	5
Communication	2	5	0
Features of old building	4	4	8
Residents´ own renovations	2	0	0
Inoperable tools	3	1	0
incomplete tasks	10	1	0
Planning of operations	20	13	3
Routings	2	0	13
Materials	8	0	1
labor resources	3	3	0
customer´s changes	2	5	10

What comes to a project III biggest trouble category – routings, it could be deduced that better up front inspecting of different potential scenarios with workable solutions, may have eased the situation with routing problems. It could be thought that planning of operations has quite direct link to routing issues, since issues with routing are basically results from lacking workable solution in certain case. And vice versa, if workable solution is available, problems with routings could be basically avoided.

If other notable categories from Table 8, such as changes of customer and features of old building, are regarded main issue seems to be majorly related to a management of variability. These factors have effects on operational level – what should be done or which tasks should be carried out? Variability on tasks at certain location might not interfere operating of labor per se, if installers only know which tasks are needed. The problems seem to occur more on management level, since system with variable outcomes is harder to monitor and control. Management seems to struggle with determining varying tasks for certain location. For example, in project II, two kitchen furniture were demolished and disposed of, even though the furniture were intended to be installed back. Wrong task was executed in wrong location. Confusion takes place more easily if manners are not systematic. Other factor causing variability on tasks emerges if offsets at certain location do not match with assumed ones. Thus, the compilation of required tasks (solution) should be reconsidered. Once again, variability of operating appears and probability of errors increases.

For the deviations in assumptions, theme of anticipation becomes relevant. As project faces different unpleasant surprises causing variability to processes, question is – how many of these surprises were truly unexpected and how many of these could have been detected and handled properly in advance? If every problem is required to escalate before action, the risk is that suddenly there are more issues on a table than system can handle. That procedure could be considered reactive. Other approach could be proactive procedure, where potential risks are attempted to sift as soon as possible to understand which factors may generate troubles i.e. variability to process. Thus, number of truly unexpected surprises, that tends to confuse performance of site, could have been decreased.

Feature of undetermined work also interfered performing on sites. Since so much work/tasks were not literally determined (only on some actors' minds), several interdependent challenges emerged. Undetermined and abstract entities may be difficult to perceive. Undetermined tasks are difficult to schedule and allocate for labor. Progression of undetermined tasks is hard to monitor and control. Risk to forget some tasks may be more likely if the tasks are not determined. Performnce at site seems to be memory based indeed.

5.5 Detected solutions and tasks

This section presents the detected operation solutions and involved tasks. During investigation phase of case projects, in all 58 different solutions (presented in appendices) were located and determined. Different operation solutions were detected from case projects by observing how different sites accomplished operations in different circumstances, for example how new building service systems were routed to one kitchen. First, task was to itemize performed operations and then divide them to separate operation solutions. During this process, one main matter to consider was the boundaries of separate solutions – where one operation solution ends and another begins. The configuration of solutions is presented in next chapter.

Relatively large number of different solutions could be explained because several solutions are location specific. Solutions demonstrates how different building service systems are imported to apartments and what different tasks are operated in apartments. For example, one solution demonstrates how vertical sewer line is imported to apartment and other solution demonstrates how sewer is routed from line to a kitchen. Solutions were divided in four different categories and in this context these categories are called *elements.* The four elements are:

- Sewer
- Water
- Electricity & Data
- Ventilation

Distribution of solutions is presented in Table 9. Like table shows, solutions were distributed quite evenly on first three elements. Ventilation contains clearly least solutions. However, these solutions considering electricity & data are considerably smaller as entity (number of different tasks) compared for instance to solutions among sewer element. How these different solutions are defined and constructed is concerned in next chapter.

Table 9 Solutions divided in separate elements

Element	Electricity & Data	Sewer	Water	Ventilation	Sum.
Number of different solution	18	14	19	7	58

Number of located and determined task was in turn 89. The tasks were divided in eleven separate categories as Table 10 shows. Tasks are categorized by the nature of work description. Some of tasks are directly linked to a certain element, like many tasks in routing & installation category, but also many tasks are independent from any element i.e. these tasks occur in several solutions and elements. At this stage, tasks are not either directed or categorized to specific actors such as tasks of plumber and tasks of demolition man. Task are rather identified and gathered. Hereby it is possible to observe the content of one solution in task point of view as well as compare two different solution in terms of tasks. This elaboration is executed in next chapter.

Table 10 Tasks divided in different categories

Category	Number of tasks
Covering	5
Demolition	19
Perforation	7
Routing & Installation	28
Carpenter works	8
Insulation works	3
Masonry works	3
Casting works	2
Fire seals	8
Tiling	3
Painting & levelling	3
sum	89

As the second phase of the research is finished and utilitarian solutions and actual task are determined, it is possible start to generate standardized operation solution model – the new construction of this research (Figure 19).

Figure 19 Structure and progression of the research

6 Construction of solution model

In this chapter the constructed model is presented. Principles of model are conducted by concerning theoretical and practical factors explored in chapters 3 and 4 to gain more holistic perspective of construction production. Also, objectives that are intended to obtain via standardized operation solution model are presented in this chapter.

6.1 Principles of solution model

In this section, the principles of operational model are introduced. First, the basics for which the model is based on is introduced. Then the configuration of solutions is demonstrated.

6.1.1 Basics of the solution model

By determining more accurately - what should be done and where it should be done, operational performance could be improved and that way productivity of assemblers could be enhanced in pipe renovation projects. – Koskela and Koskenvesa (2003) demonstrate production planning issues concentrating in too uncritical comprehension of general schedule, inaccurate task descriptions and ineffective production control methods which do not focus on root causes of problems, as these root causes may derive project to state where production is managed unsystematically and according to a situation. Koskela and Koskenvesa (2003) claims that before mentioned situation may also lead to a point where decision making is left for separate work groups. As a result of this, productivity decreases inevitably (Koskela and Koskenvesa, 2003). After reviewing construction production from theoretical and practical perspectives, the issue that is intended to be solved concerns poor production information.

More accurate planning could provide benefits on several areas. Increased reliability of plans and proper production strategy tends to enhance subcontractors attitude for certain project, which could be manifested as better providing of resources to the project and more cooperative behavior (Sacks and Harel, 2006; Bertelsen and Sacks, 2007). Loosemore (2011 p. 257) claims that more precise plans and effective information distribution should increase productivity of subcontractors as well. It could be assumed that uncertainty in dynamic environment full of variability partly prevents productive performing. If plans are received viable and reliable, plans might also be utilized more and production may become more efficient. Matter of reliability and viability are emphasized as Bertelsen and Koskela (2004 p. 7) express that generally operational plans are based on idealized and simplified assumptions which do not reflect reality and hereby provides rather insufficient information and poorly practicable solutions.

How the solution model is constructed will be discussed next. Like, Sacks (2016) demonstrated in PPO model, process and operation flows should be separated from each other and to gain more prominent improving in production, perspective should be process oriented. Thus, this model strives to create certain kind of link between process and tasks, in which information is in the main part. Simplistically demonstrated, one location represents a product and thus the location is an object of process. To produce a product, specific tasks should be executed. These tasks are structured and organized by operation solutions. The constructed model clearly utilizes work breakdown structure (WBS) features (Norman, Brotherton and Shelly, 2008), especially concerning the structure of model. To perceive the process for one location better, the tasks are connected for certain solutions to provide clarity and structure as well as to facilitate the operational planning of one location. Figure 20 present the architecture of operational model.

Although Sacks´s (2016) PPO model provided relevant frames to consider the construction production, it does not take a stand on the information segment, which raised up to be an issue in empirical observation. Model in Figure 20 could make it easier to understand how general contractor and sub-contractors perceive the pipe renovation project. General contractor interest should be in process/locations area and subcontractor interests more on operation/tasks area. However, as observations in chapter 4 indicate, the operational contents are hardly considered (there are no determined tasks in ´operations´ area), which leaves subcontractors in quite awkward position.

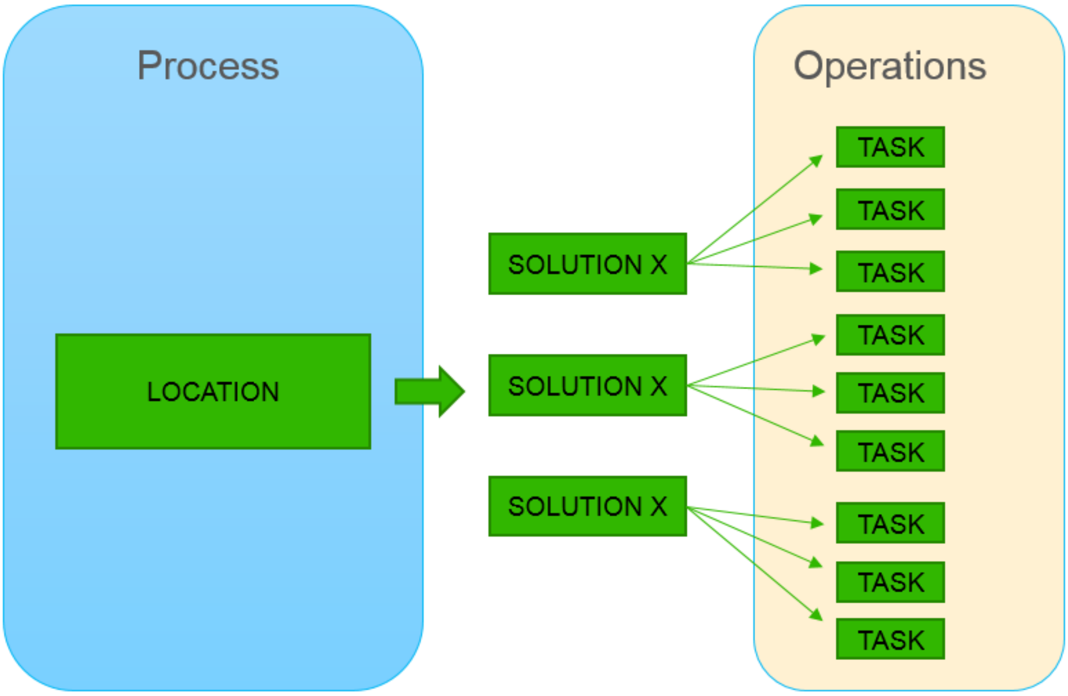

Figure 20 Architecture of operational model

As basics of operational model are now introduced, next intention is to open solutions more. Next section discusses, how solutions should be constructed, and what factors may have influences to solutions.

6.1.2 Configuration of solutions

Different solutions are gathered by monitoring how different projects, in last chapter, solved the problems concerning the installing and routings. Thereby, these solutions are already found to be workable in practice. However, contents or boundaries of these solution are not investigated yet precisely. To provide better information about work and tasks, configurations of solutions should be understood better.

Basically, we have a need that should be fulfilled. In this context, it could be thought that these needs are concerning earlier presented elements including sewer, water, electricity & data and ventilation and three different factors (wishes of customer, regulations and features of building) producing major impacts to certain need. To fulfill the need, there should be solutions. Different solutions should provide answer to a question – how certain need is fulfilled, in other words, how certain operation is carried out. Figure 21 demonstrates this interaction between needs and solutions. This interaction produces certain border conditions for one solution since these factors mainly determines the desired end results of process. For example, customer likes to determine the location of sink in kitchen. So, the sewer pipe should be routed to sink. However, exiting building determines abundantly where sewers are reasonable to place, like where is enough space. In addition to this, regulations determine how certain structures could be modified and what requirements certain structures should fulfil, for example fire classifications. Pointedly, one or more solutions determines how the sewer is eventually routed to the kitchens sink and which tasks should be accomplished to enable this.

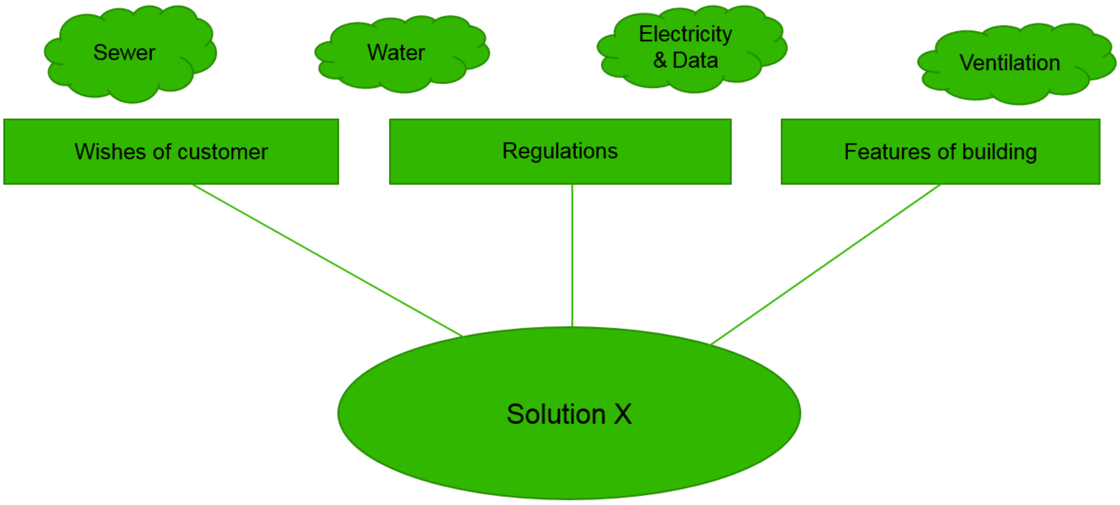

Figure 21 Influences for one solution

Naturally next question is - what are the demanded tasks? In this context, it is considered that one solution activates particular tasks in conceptual ´task space´, demonstrated in Figure 22. However, in this research idea is to examine what kind of task combinations certain solutions activates. Also, may certain extra demands of location activate more tasks. For example, if ostensibly the same solution is implemented in different locations, is there variation in implemented tasks, and if there is, how much variation occur in task entities. It could be also possible, that in favorable circumstances some tasks are not even necessary to operate. More accurate answers to these questions should be gained after validation phase, where these predetermined operation solutions are first time tested in practice.

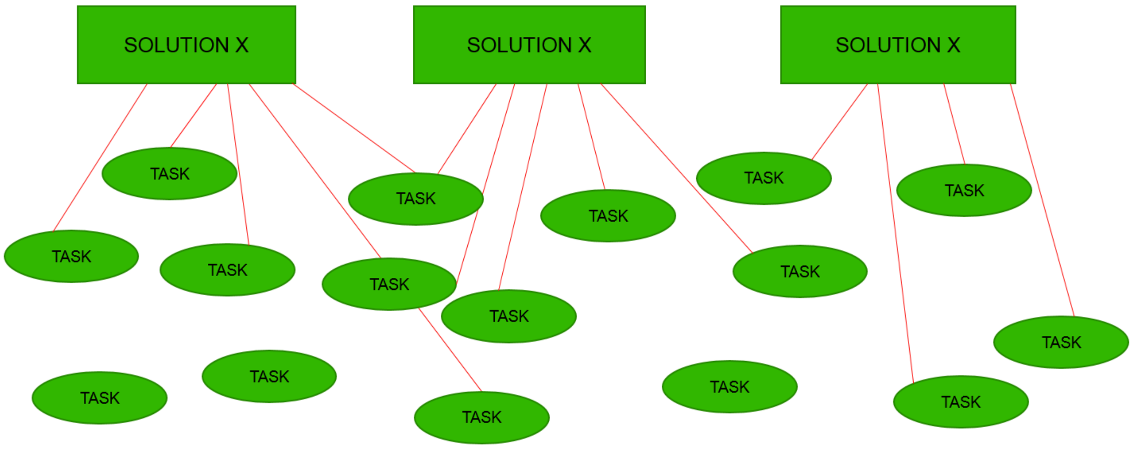

Figure 22 Red line demonstrates the idea of which tasks certain solution activates in `task space`

Definition for solution is – method to fulfill operation. One solution answer to a question – *how* operation is done. Operation in turn presents – *what* should be done. As a practical example, operation – horizontal sewer pipe from vertical line to a kitchen sink (what), solution – route for horizontal sewer pipe is drilled in the floor (how). As answer to a question – *how,* changes substantially, other solution takes place. This is also border between two standardized solutions – same operation is executed differently because of varying conditions at different locations e.g. two kitchens. At this stage, solution also reveals which tasks it contains, but descriptions for tasks are not inside the frame of this research, since main focus is in standardizing the solution.

6.1.3 Objectives of model

In this section, objectives of constructed model are demonstrated. Intention is to answer the question – what is strived to achieve with this model?

First, let´s observe the process model of target company. Process model of Fira Palvelut is presented in Figure 23. Model is very installer-oriented as it states – to achieve good productivity, all requisite information and materials should be provided for installer timely. Idea seems to be that, if operational preconditions are not in order for installers, there is no prerequisite for effective operating and hence, for good productivity. The four distinct factors of model providing effective work of labor are right information concerning the tasks, functional location based schedule, effective quality assurance and workable logistics. In this context, one objective of solution model is – generate frame and basis to be able to create task descriptions. With this constructed solution model, it is possible to derive task from need, i.e. the model creates bridge between need and task (Figure 24). Every task is under one solution and every solution is under certain location. In turn, every location contains its own needs. With this model, every task has its own `address`– where each task belongs. This feature of ´address of tasks´ could be utilized and improved further in future. From this point of view, contribution of research is allocated to arrow number one (Figure 23) - factor considering the information of process.

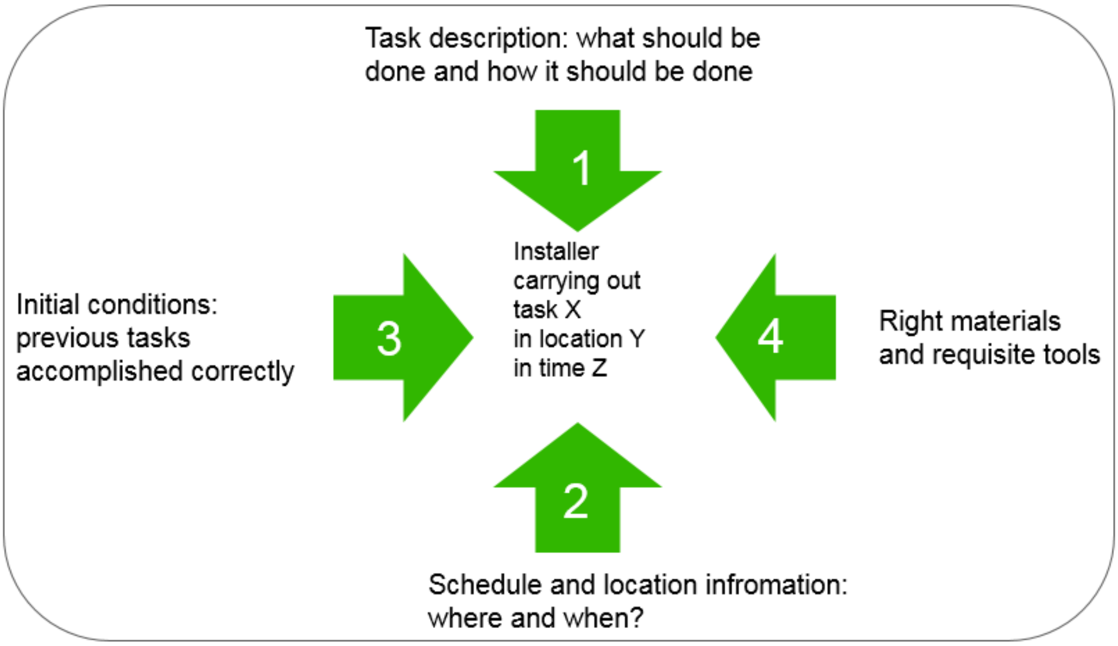

Figure 23 Process model of Fira Palvelut

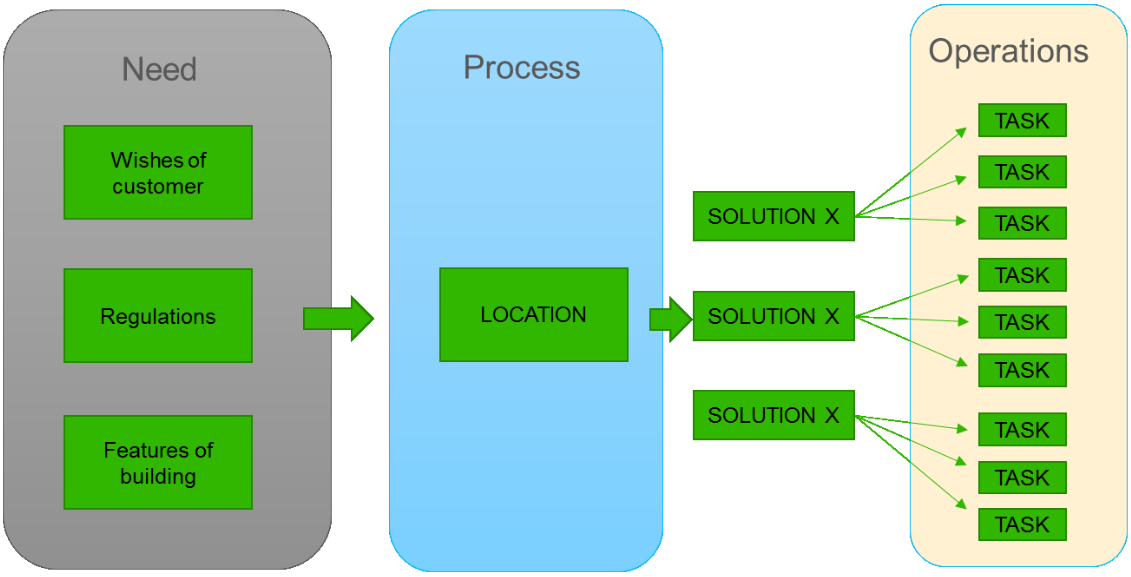

Figure 24 Solution model could create connection between need and task

On the other hand, as tasks of operations are determined by standardized solutions, it could be more sensibly to allocate resources, for both – general contractor and subcontractors. By determining only required result of processes, the actual content of work would be hard to perceive. Plainly, the solution model should convert imprecise information to operation plans. Ideally, these plans should reflect the content and amount of work.

As it is possible to do same thing in many ways, one objective is to pinpoint the most practical and effective solutions to accomplish operations. For instance, two different solutions may lead to the same result. However, the content of these two solutions may vary on number of tasks, difficulty of tasks and the impact of one task to another task. Therefore, operations could be done either easy or hard way. As Koskenvesa (2011 p. 138) demonstrates, in construction projects, skillful and professional actors are needed and their experience should be exploited. Thus, as workable solution occurs in pipe renovation site, solution should be documented and shared with other projects for utilization. The ´islands of information´ (Dave *et al.*, 2008) as phenomenon seems to reign between different project groups, since information does not flow sensibly between different projects. Information and practical know-how seems to conduct majorly through people, as actors shift to new projects with new project groups. Such distribution of information does not compute, since it is slow and some actors may not reach the information. With this model, workable solutions could be shared with wider group of people.

Final, and maybe the most significant contribution of this model associates with management of variability. As observations in previous chapters indicate, it is variability in processes that causes vast amount of issues and waste in production. In pipe renovation context, it would be rather misleading to talk about elimination of variability. Control of variability would express better the situation. More precisely, in pipe renovation project, it is hard to eliminate several sources of variability, since the environment where operation takes place (building) already exists and its certain features may not be affected directly. However, the methods for managing different situations could be standardized i.e. controlled. As Modig and Åhlström (2013 p. 142) express it, by standardizing common methods, variability in how we do things, could be decreased. Thus, as solutions are standardized, certain situations are carried out with predetermined solutions. Therefore, one thing could not be done in many ways anymore.

6.2 Construction of solution model for the test project

In this research, standardized solutions encompass mainly operations in apartment´s other rooms than bathroom. Argument for this procedure is that in bath rooms processes are determined and refined comparatively further than in other rooms. Operations in other rooms, such as in kitchen, vestibule and living room, are quite vaguely determined. Therefore, these locations of apartment tend to be in blind spot for operating during renovation phase. Since solutions and tasks are not determined for these rooms/locations, efficient production may remain uncertain. Without determination of tasks total amount of work in certain apartment is rather assumed.

The current state of mind assumes that rooms of different apartments on top of each other are basically the same, like copies of each other that could be treated with same solutions. In 2-dimensional architect pictures level, different apartments may even look like duplicates. However, the real situation in apartments may diverge enough from preliminary assumptions to make assumed solution impractical. As these problems occur during the renovation phase, management have to react and cope these issues. This problem solving during renovation phase consumes lots of time and energy of management and therefore also causes waste. One way to consider perspective of site management is presented in Figure 25. Site manager should control the process per plans. As situations, do not responds to the plans, issue has emerged and site manager should solve it. During the issue, operating usually interrupts and waste begin to accumulate as couple actors are thinking and others are waiting. After indefinite time, problem is hopefully solved and operating shall continue. Example was somehow caricatured, but the point was that reactive procedures may increase waste. And on the other hand, even somewhat simple situations may turn into a problem if situations are not considered/planned enough (in this context, solutions are not determined). If management´s day at site is consisting more on solving unexpected situations (reactive) than implementing plans (proactive), one reason seems to be in inadequate opearation planning. Either plans do not provide enough information, or plans do not even exist. Thus, standardized operational solution model aspires to provide more plans to act proactively and decrease need to solve problems reactively.

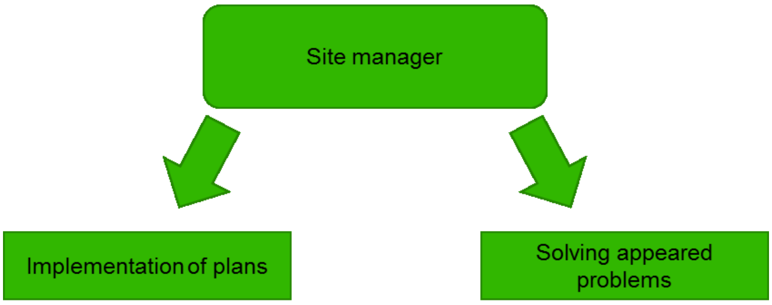

Figure 25 Perspective of management in pipe renovation site

6.2.1 Standardized solutions for the test project

In constructive research approach, the constructed method should be tested in practice. In this research the testing takes place in actual pipe renovation project. The target project contains 16 apartments. Other features of building are introduced more precisely in next chapter as purpose of this section is to demonstrate the process of solution determination. Intention is to present how information, to determine appropriate solutions for particular locations, was collected. The collection of data was three-stage process (Figure 26) wherein the ambiguous data was strived to convert to more explicit information.

Figure 26 Data collection process to determine operation solutions

In first phase, project plans and building service plans were investigated. Practicality of plans and potential problematics were localized and elaborated. Based on these plans, first initial solutions were determined for each location. Underlining word initial, since all requisite location specific information concerning feasibility of solutions could not be obtained from these plans.

In second phase, each apartment was explored on the spot before renovation phase. This procedure enabled three-dimensional real time review of locations. As apartments were able to be visited, features of them were discovered more precisely, like order of furniture and appliances and locations of exhaust valves and sinks. Only conditions inside structures remained as mystery until demolition works began. Especially the question, which plans in first phase left open were checked on visits. Based on this information, most of solutions were able to be determined. However, questions that required customer´s special plans, like kitchen renovation, left open until the plans were complete and signed by the customer.

As majority of operation solutions were determined, requisite tasks were allocated for each solution. Hereby, first actual versions of standardized operation solutions were generated.

In third phase, as the `final` plans, approved by customers, were official, the rest solutions could be determined and tasks for them as well. Hence, the first attempt to determine operations, at other rooms than bath room, by predetermined solutions was done.

6.2.2 Evaluation of standardized solutions

As requisite information of locations was gathered, the workable solutions were determined for each apartment. The compilation of solutions for certain location was produced from earlier defined solutions, from source projects in chapter four. Also, needed tasks were allocated under standardized solutions. In this section, the solutions implemented in test project are analyzed. Intention is to observe how many different solutions were needed to accomplish operations considering each element - how frequently certain solution was required? As earlier mentioned, operations for bath rooms are neglected in this context. The locations/rooms where the operations take place in test project are:

- Vestibules
- Kitchens
- Toilets
- Living rooms
- Bed rooms
- Partly bath rooms (if routes go through it)

In all, 27 different standardized solutions were determined for 16 apartments (Table 11). Thus, almost half of predetermined solutions (58) were applicable in these locations. Most different solutions were determined for electricity & data element and least for ventilation. Next, selected standardized solutions are presented, as well as incidence of each solution.

Table 11 Number of different standardized solutions determined for test project divide by elements

Element	Electricity & Data	Sewer	Water	Ventilation	Sum.
Number of different solution	10	6	8	3	27

First, Table 12 presents selected solutions concerning element electricity and data. Table also demonstrates incidence of each solution. Averagely, each apartment contains nine different solution for electricity & data works. Each solution is connected for certain location, which in this context are different rooms of apartment. Thus, each solution determines, how required operations are accomplished in particular locations (rooms). For example, operation concerning electricity & data in vestibule is to route electric wires from switchboard to a ceiling of bath room. The operation is carried out with one or several solutions presented in Table 12. In test project, most commonly used solution seems to be no. 2 ` *Electric wires at ceiling boundary in plastic casing*` (used 28 times) as solution no. 8 `*Lifting of electricity wires behind cabinet*` should be used only five times. Other solutions seem to incidence quite evenly from ten to nineteen times. However, validation phase in test project evidences how these solutions are implemented in practice.

Table 12 Selected standardized solutions and incidence of them for electricity & data

	Electricity & Data	
No.	**Solution**	**incidence**
1	**Shifting of switchboard**	10
2	**Electric wires at ceiling boundary in plastic casing**	28
3	**Electric wires at floor limit in plastic casing**	13
4	**Electric wires at upper plinth of cabinet**	18
5	**Electric wires through wall**	12
6	**Electric wires in ceiling**	19
7	**Electric wires at lower plinth of cabinet**	11
8	**Lifting of electricity wires behind cabinet**	5
9	**Lifting of electricity wires in plastic casing**	16
10	**Lifting route of wires drilled on bath room wall**	12
	Total	144

Second element under evaluation is sewer. The selected solutions and incidences are presented in Table 13. As table shows, the most commonly used solution is no. 5 `*Sewer branching at basement level*` with 16 utilization times. In turn, solution no. 3 `*Diagonal diamond drilling into a ceiling of lower apartment´s bathroom*` should be used only one time. Notable is that, operations concerning sewers should be carried out with quite few solutions, but nevertheless, in some locations there are still need for some more unique solutions, to fulfill the needs.

Table 13 Selected standardized solutions and incidence of them for sewer

	Sewer	
No.	**Solution**	**incidence**
1	**Existing duct**	8
2	**Branch from vertical line**	3
3	**Diagonal diamond drilling into a ceiling of lower apartment´s bathroom**	1
4	**Sewer branching in ceiling of lower room**	2
5	**Sewer branching at basement level**	16
6	**Sewer pipe at lower plinth of cabinet**	9
	Total	39

Third observed element is water. For water, there is not any remarkable peak of one particular solution (Table 14). Utilization has distributed quite evenly on most commonly used solutions. But, like for sewer, there are also need for some separate solutions including no. 4 ` *Water pipes in floor casting of bathroom* ` and no. 7 `*Branching of water pipes in ceiling*` (Table 14).

Table 14 Selected standardized solutions and incidence of them for water

	Water	
No.	Solution	incidence
1	New duct	9
2	Branch from vertical line	8
3	Water pipes at lower plinth of cabinet	7
4	Water pipes in floor casting of bathroom	1
5	Lifting of water pipes at casing structure	2
6	Branching of water pipes on wall	8
7	Branching of water pipes in ceiling	1
8	Water pipe branching at basement level	5
	Total	41

Fourth, and final element under evaluation is ventilation. As Table 15 approves, ventilation could be considered as the smallest element. Maybe for that reason, role of ventilation tends to gain less attention during renovation phase. Therefore, ventilation may cause problems since its requirements are left to be considered last, when different options to act are usually already declined. If requirements of ventilation are sufficiently considered beforehand, some redundant issues could be avoided. In test project, ventilation operations should be carried out with three different solutions (Table 15).

Table 15 Selected standardized solutions and incidence of them for ventilation

	Ventilation	
No.	Solution	incidence
1	Reorganization of ventilation ducts	7
2	Renewing of exhaust valve	14
3	Valve attached to modified cabinet door	3
	Total	24

Test project´s solutions with involved tasks are presented in appendices. As total, 248 solutions were determined for locations of the test project and third phase of the research is finished. Next step of research is validation phase, in which constructed method is tested in practice (Figure 27).

Figure 27 Structure and progression of the research

7 Model validation through implementation

In this chapter, major theme is implementation of constructed solution model in practice. Observed outcomes and insights during validation phase are also presented and evaluated. First, the test project is introduced more precisely, as well as implemented methods to measure and analyze functionality of solution model.

7.1 Introduction of target project

In this section, project, target building and its features are introduced. Building under pipe renovation is apartment house constructed in 1970. The building contains three floors and four stairwells. At base floor, there are 20 garages and pipe channel. New horizontal sewer and water main lines are placed in pipe channel to replace the old ones. 16 apartments are at first and second floors. Frame of a building is casted in situ. In apartments, building service system is majorly embedded in structures. Building contains natural ventilation and ventilation ducts are implemented with prefabricated concrete flue elements (four ducts per flue element. Old vertical sewer lines also locate in these ducts.

This project focuses on renovation of bathrooms, toilets and building service systems. Also, some modification works are executed in common spaces such as pool department. Every bathroom and toilet will be renovated. Water and sewer systems will be renewed as vertical sewer lines are replaced in already existing ducts but vertical water pipe lines are shifted into new locations (new ducts will be built). Also, plot interfaces will be renewed. Exhaust valves will be renewed and some ventilation ducts must be rearranged. Electric and telecommunications systems are renewed and routes utilizes the new water pipe ducts/routes as much as possible. In kitchens, electricity of stoves is renewed with new three-phase electricity supply and one extra supply is provided to kitchen.

Essential aspect considering the operational planning is that the apartments on top of each other are not identical. Thus, the requirements and border conditions should be considered more carefully than usually in apartment houses, where same layout is repeated from floor to floor. In this building, certain similarities are shared rather between apartments at same floor.

The schedule concerning the renovation works of apartments is planned in a way that works starts in first eight apartments in week 33 and in last eight apartments works starts after three weeks (in week 36). Originally each apartment has eight weeks' lead-time, so the renovation phase of apartments should take at most 11 weeks.

7.2 Methods

The progression of renovation phase is observed on the spot. In this situation, this should be the most effective and reliable method to gather data and monitor research subject. Features under monitoring are:

- Reliability of operation solution – Are predetermined standardized operation solutions including tasks feasible in practice or should other solutions be used instead?
- Completion of tasks – When predetermined tasks are accomplished?
- Problems with planning of operations – Do operational plans face changes, what kind of and why?
- Problems of project in general – What kind of problems occur in project?

Intention is to explore effects of standardized solutions to production. The hypothesis is – issues concerning planning of operations should not emerge barely at all in locations where standardized operational solutions are determined. This means that management should not struggle with question - how operations are fulfilled in certain locations during renovation phase. Possible scenario to cause variability to content of solutions could be factors inside the structures, which cannot be find out beforehand. Therefore, these factors may change the assumptions on which certain standardized solution is based. Other possible scenario for variability could be the erroneous assumptions of location´s features.

Progression of production is monitored by tracking the completion of tasks of standardized solutions. Completed tasks are reviewed weekly in every apartment. With current methods and resources, monitoring of separate task (used time or work realizer) is not possible. State of site and occurred problems are observed and documented on the spot three to five times per week. One question before validation phase is – do emerged problems during renovation phase distribute differently, compared to projects in chapter 4, as solutions for operations are determined beforehand? After renovation phase of apartments is ended and requisite data gathered, outcomes of test project could be analyzed and discussed.

7.3 Implementation

This section demonstrates how solution model is implemented in test project. Reasonable utilization of information, provided by the constructed solution model, requires close collaboration with site management, since site management is decision making organ at operative level. This collaborative procedure is typical in constructive research approach (Lukka, 2001)

As site management coordinates production on pipe renovation site, question is – how information provided by standardized solutions could assist site management in decision making and production management, to ensure efficient production on site. Figure 28 demonstrates the process considering the utilization of solution model between different actors. First, researcher gather information about locations. After that, researcher selects usable standardized solution/solutions for location. Aforementioned procedure creates direct information for planning of operations. That information is shared with site management, who could utilize it in production management. Finally, installers actualize the plans, i.e. carry out the tasks. If this chain function correctly on every stage and between every actor, problems concerning operations itself (unworkable solutions and task on certain location) should not emerge during production process. On the other hand, if some stage is accomplished incorrectly or chain of collaboration and communication between actors breaks down in any stage, negative impacts may occur at the latest in operating stage. For example, if observation of location is done inadequately, probability that unworkable solution is selected increases. If, solution is workable, but information distribution is dysfunctional, the right tasks may not reach the installer.

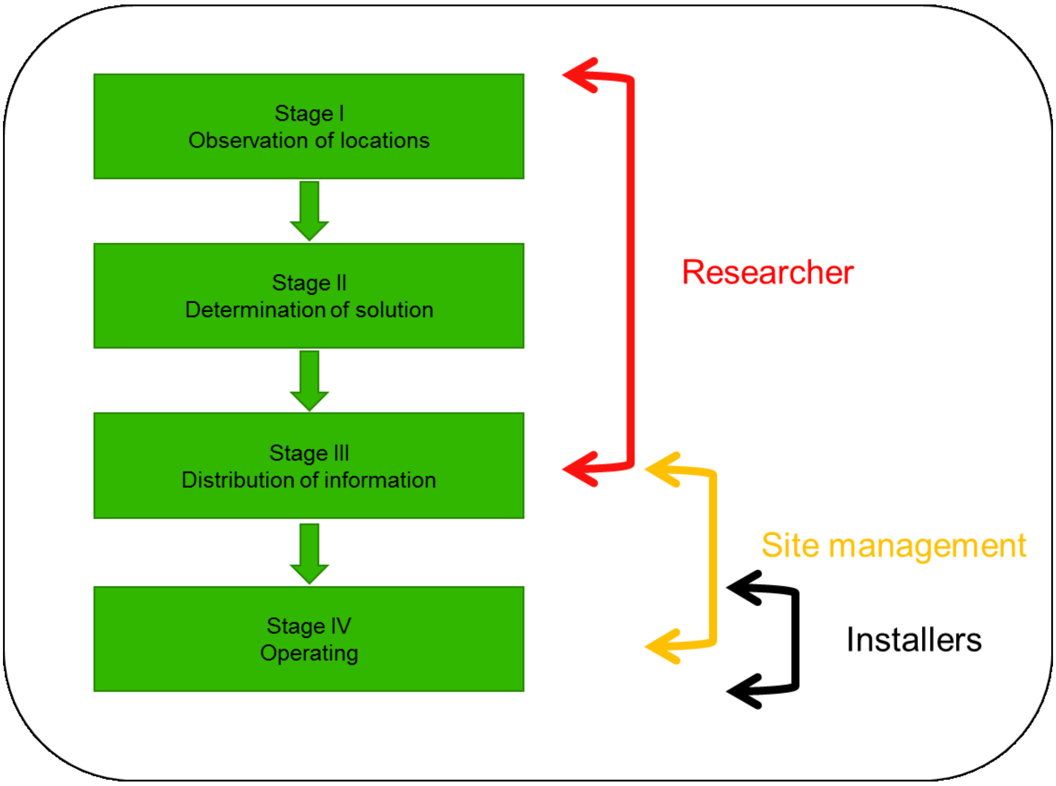

Figure 28 Implementation of model on site

Observations in chapter 4 indicates that Stage I and Stage II (Figure 28) has been left for less attention. This may cause problems at operating stage. Without requisite information, management´s capability to select practical solutions is difficult. This lack of information seems to cause unnecessary hullabaloo in production, on other words waste and decrease of productivity.

In test project, selected standardized solutions and task were scrutinized with site management, before renovation phase. Solutions and involved tasks were sorted apartment specifically. These lists with solutions and tasks were divided into each apartment for everyone to see. In addition to this, for each solution list there was also building service plans where most significant and exceptional notions were marked, such as standardized solutions for sewer and water. Site management also possessed these documents in site office. With this procedure, intention was to prevent concentration information in site office and distribute information wider on site. Moreover, as information is distributed also to locations, need to memorize special cases diminish and information is not relying only on certain actors' memory.

Apartment specific lists also revealed the amount of work for each apartment. The differences between amount of task were considerable. Apartments with higher workload, even 59 different tasks were determined. Apartment with lower workload, included only about 27 different tasks. Thus, it could be roughly evaluated that some apartment requires double amount of work compared to some other. If operating in other rooms than bathrooms is not determined, and if work contents of apartments could vary as much as presented, it should not be surprise that planning of operations may cause issues, like source projects indicate.

7.4 Results

In this section, results of testing phase are presented. After that, the results are analyzed and discussed.

First findings concern monitoring of test project and data collecting. As pipe renovation site is dynamic production environment, monitoring of site raised certain problems. Activities on site are distributed on wide area – something is going on somewhere, all the time. As monitoring of operations and outcomes is mostly based on sensory impression, several cases and issues may pass unnoticed. In other words, if you are not concretely on the spot when something happens, it could be hard to document these cases correctly afterwards. On the other hand, as several operations are not determined or standardized, monitoring or scheduling these operations is awkward indeed. For these reasons, it is challenging to measure more detailed factors at pipe renovation site.

During validation phase, one new solution was identified and utilized on site. This example illustrates, why this constructed model should be flexible, in terms of evolving, to respond to dynamic production environment. In this solution, existing electricity routes inside structure were utilized. Therefore, making new electricity routes were not necessary at certain locations and therefore, some of predetermined solutions were redundant. This option reduced amount of needed work. However, problem with this new solution is that utility of it is basically impossible to determine beforehand, without trying. Thus, relying only on this new solution is uncertain. Therefore, also alternative solutions should be determined, which could be rejected, if existing electricity routes are exploitable.

Otherwise, predetermined operation solutions were majorly correct. In three cases, existing vertical sewer line was in different location (duct) than plans presented. As earlier assumed, these cases were in category – issues inside structures, which are rather awkward to detect beforehand. However, although the sewers lied in different locations than assumed, the standardized solutions remained the same. The location for tasks only shifted (tasks allocated to kitchen shifted to toilet). Only one out of 248 predetermined standardized solution was replaced to another. In one kitchen, new exhaust valve was attached to upper plinth of kitchen cabinet instead of modified cabinet door, where old valve originally lied.

In all, 642 predetermined tasks were completed in nine weeks. Figure 29 present the distribution of tasks per one apartment. The varying in number of tasks is majorly caused by extra toilets in certain apartment, that involves certain operations (tasks). Basically, apartments without separate toilets contained less locations (products), and therefore also fewer tasks. Other factor decreasing the number of tasks was customers´ own kitchen renovations, implemented after pipe renovation project. On the other hand, common factor increasing number of tasks was extra works concerning electricity & data in apartments.

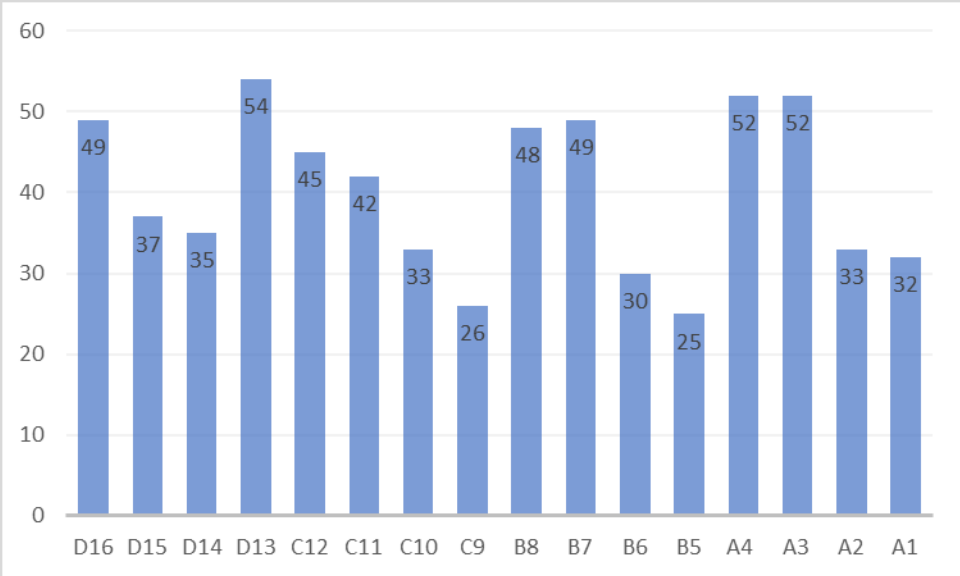

Figure 29 Distribution of completed tasks per apartments

In Figure 30, number of accomplished tasks per one week is presented. First perception is a relatively large number of accomplished tasks, that have not been clearly determined earlier. That amount of tasks have been carried out somehow more or less unsystematically and without scheduling, as focus has been majorly in production of bathrooms. It is unquestionably true that bathrooms contains more work than other rooms of apartment. But as results show, the amount of work in other rooms is nonetheless prominent, as well as varying demand of different solutions. Neglegting this segment of work may and will casue issues for production as chapter 4 reveals.

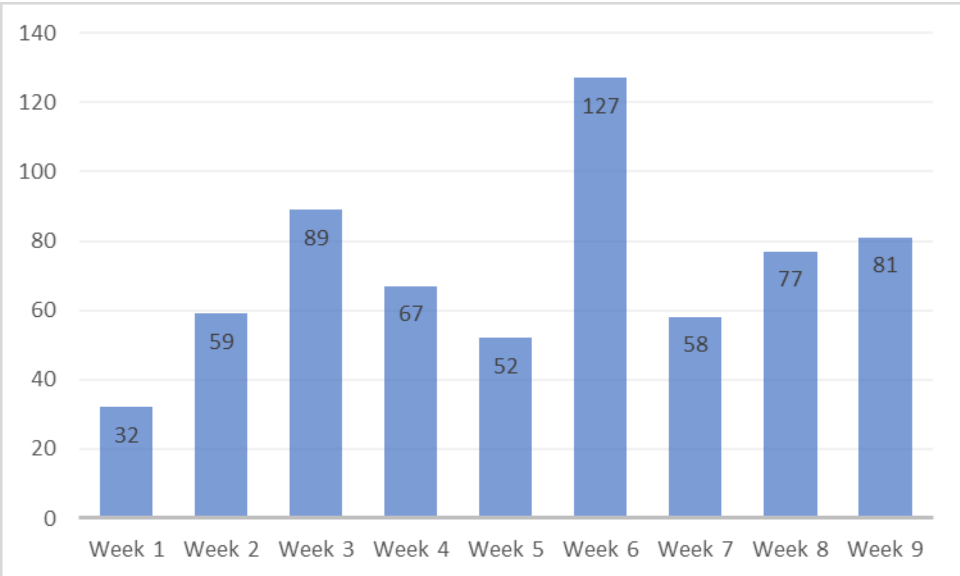

Figure 30 Distribution of completed tasks per week

Figure 31 presents distribution of task per week separated for each apartment. Considering the task peaks on weeks 3 and 6 the major reason seems to be the completion of several electricity & data tasks, which are relatively lighter, smaller and faster to carry out than several other tasks. Otherwise, number of weekly accomplished tasks is quite steady and regular. However, these charts do not reveal the amount of completed work in bathrooms, nor in common spaces such as basement, pipe channel or garages.

As Figure 31 shows, completion of predetermined tasks took approximately six weeks, regardless of the number of determined tasks. The other rooms of apartments completed mainly at the same time with bathrooms, although the amount of work was smaller in other rooms. Possible reasons for this is discussed in next section.

What comes to reliability of predetermined tasks, 9 tasks out of 642 were replaced to more workable tasks. In these cases, perforation of wall or duct was carried out with diamond drilling instead of conventional drilling, or upper plinth of cabinets was perforated, not removed and finally, one task `ceiling` was missing for one toilet (apartment D13). After all, based on this data, reliability and accuracy of standardized solutions and involved tasks could be claimed to be quite high.

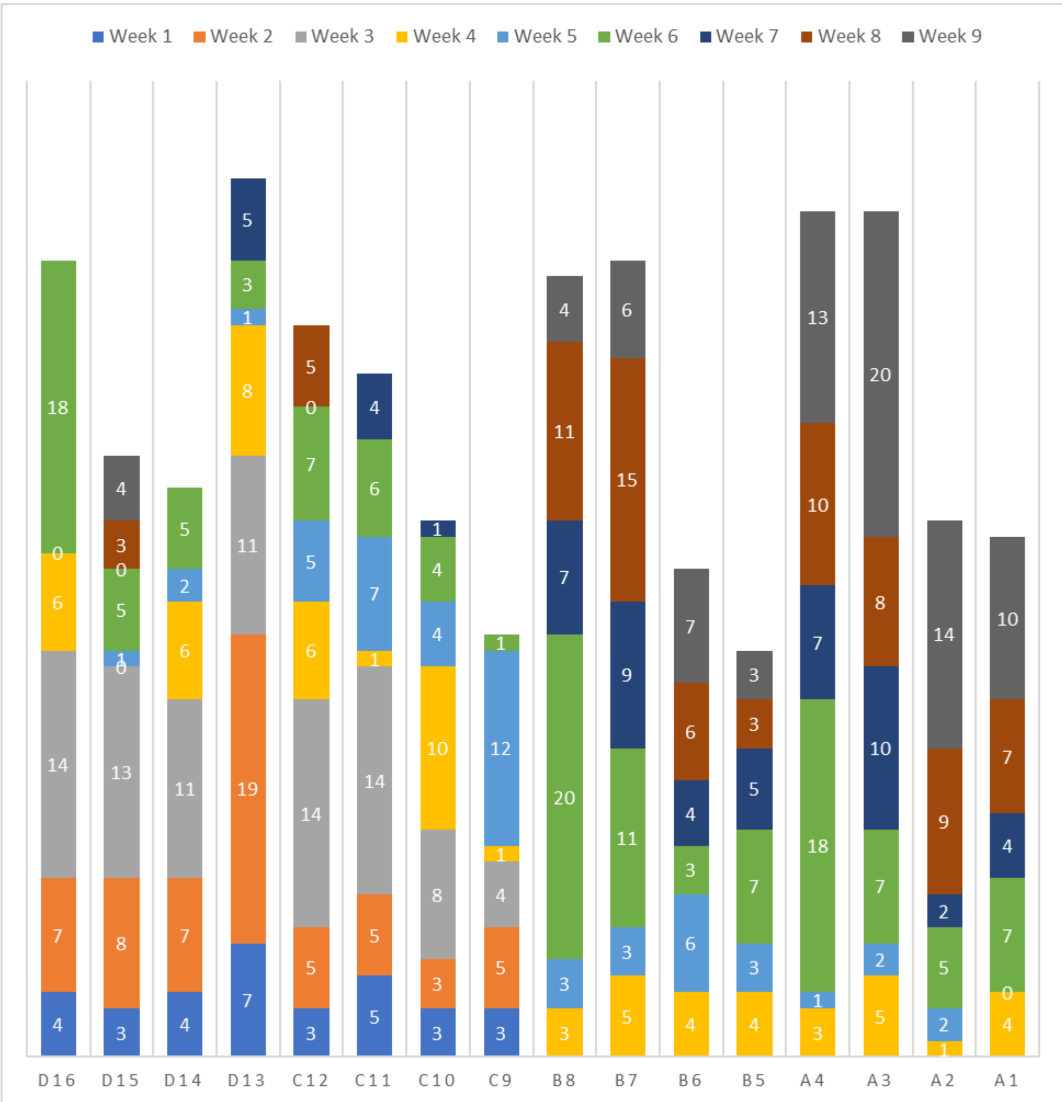

Figure 31 Number completed task per each week and apartment.

What comes to an emerged problems and issues of production in the test project, the most frequent problems occurred in category `incomplete tasks` (Table 16). Other prevalent issues emerged still in communication at site and planning of operations. This observation of emerged deviations concerns whole project, not only locations where standardized solutions were determined. For example, most problems concerning planning of operations emerged in bathrooms. However, as Table 16 presents, problems with routings were quite well tackled. But, it could be considered that the issues shifted one step further – to incomplete tasks. This outcome was somehow predictable, since this constructed solution model does not cover the task descriptions (instructions for certain task). In other words, although the tasks were determined for certain standardized solution, the accomplishment of tasks were not described unambiguously. Problems with incomplete tasks are also connected to communication issues at site as well, since, site management gave the task descriptions for labor verbally.

Table 16 Deviations and problems of test project

Category	number
Logistics	2
Site´s courses of action	4
Communication	11
Features of old building	9
Residents´ own renovations	0
Inoperable tools	1
incomplete tasks	13
Planning of operations	10
Routings	2
Materials	2
labor resources	6
customer´s changes	4

7.5 Discussion

In this section, the obtained results from testing phase are analyzed and discussed. As a first deduction based on the data, it could be stated that standardized solutions are quite reliable and workable in practice. However, attention should be drawn to implementation of the constructed model.

In test project, information of constructed model was mainly used to locate awkward spots of production, as well as places that contains potential risks to process. Therefore, issues concerning routings were avoided in locations where standardized solutions were determined beforehand. Due to this, operation planning during renovation phase were reduced significantly. However, planning of operations remained still as an issue in locations that standardized solutions did not cover.

As model was mainly utilized to clarify forthcoming demands of locations, by predetermining the solutions for each location, solution model´s other significant informative advantage – determined tasks – were not utilized as effectively as constructed model could have afforded. Operating in locations, where solutions were determined, could have been scheduled more profoundly, since the actual tasks were determined by standardized solutions. Production was managed with rather traditional manners. The prominent difference in production management was that the solutions for operations were considered and selected more accurately and beforehand. Reasonable task scheduling have been awkward before, since tasks in other locations than bathrooms have not been determined on as accurate and detailed level. The ´parts´(tasks) of which the task schedule consists of, have been missing. By standardized solutions, the required tasks for certain operation are revealed. The advantage that determined tasks provide for task scheduling, could be elaborated further in future. Interesting question is – how determined tasks could be converted to a task schedule (Figure 32)? To gain success in task scheduling, the development may require even more and closer collaboration with site management.

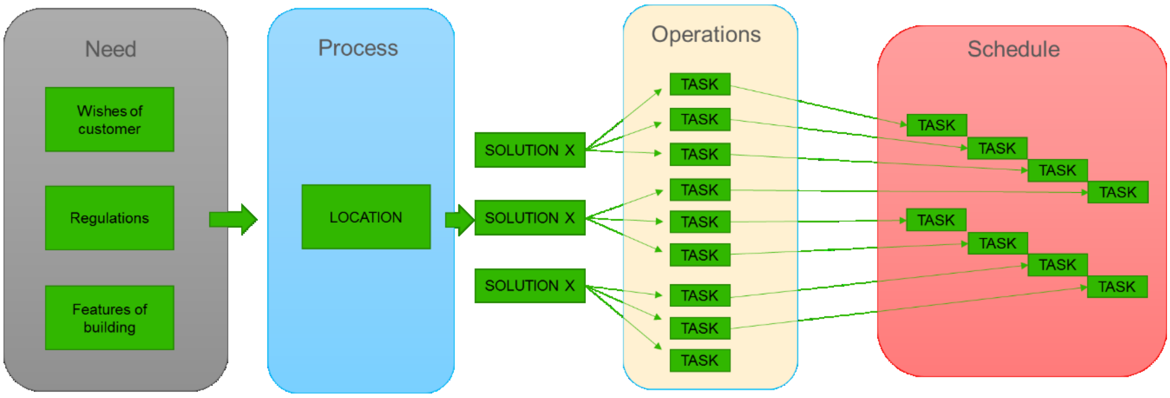

Figure 32 Future step to adapt schedule to standardized operation model

The lack of functional task schedule for locations under standardized solutions may partly explain why apartments other locations were basically completed at the same time with bathrooms. Although, other locations contained fewer tasks than bathrooms. Resource allocation may be complicated without task schedule. Therefore, production of one apartment were implemented by same work force, i.e. production of bathrooms and other locations were not operated as simultaneous as it could have been possible, since there was no distinct resources for these locations.

As results shows, the amount of work in apartment´s other rooms/locations than bathrooms is prominent enough to be concerned more systematically. By neglecting this segment of production, it might be almost impossible to improve operational performance and productivity in pipe renovation projects.

If deviation of problems in Table 16 are considered, first notion is highest portion of incomplete tasks. The biggest single factor for high amount of incomplete, or wrongly accomplished tasks, may be the absence of task descriptions – the directions that demonstrates how certain task should be carried out. That strongly indicate to findings of Siikanen (2009). However, to conclude the problem of missing task descriptions, the solution should be approached systematically, step by step. To be able to provide the task descriptions for installers/work force, the task should be determined first. No task – no task description. The standardized solutions decrease the variability in processes by controlling amount of possible solutions to operate. The task descriptions might decrease variability in processes even more by determining unambiguously – how certain task should be completed. However, the first requirement for task descriptions is that the standardized solutions are reliable and functional in practice. Thus, standardized solutions could provide solid foundation for task descriptions.

Other considerable sources of problems in test project were still planning of operations and site communication. Also, inadequate labor resources interfered effective performing on site.

These factors may somehow be connected to each other. Issues concerning planning of operations still manifests as inaccurate and unworkable scheduling of tasks and operating based improvisation. Possible reason for these manners may be the lack of requisite information. Controlling unsystematic process is awkward and misunderstandings between different groups are probable. This may partly explain the issues concerning communication. On the other hand, lack of suitable task schedule may complicate resource allocation. For the absence of unambiguous information, resource allocation might be based on experience and assumptions. As discussed, expressing the one real problem is not that obvious, since many factors are connected and interdepend.

In future, constructed solution model has potential for development and expansion as Figure 33 demonstrates. As Standardized solutions are now determined and tested, natural step forward would be addition of task descriptions to a model. By that, even better control of variability in production processes could be obtained. Other possible improvements to the model would be addition of material information, quality requirements and realizer of task. This would create the model even more comprehensive and accurate in practice. In that case, the model could provide information with higher quality for pipe renovation production.

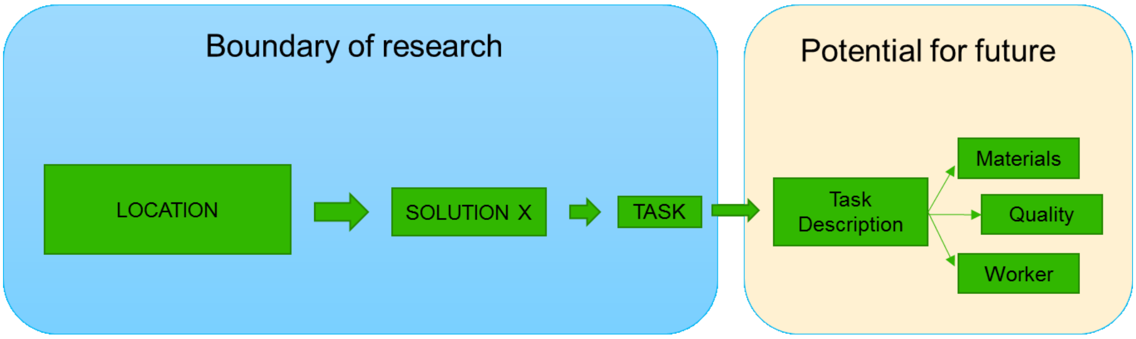

Figure 33 Prospect for future to add task descriptions and other features to model

At the moment, there might be no crucial reason why this constructed solution model could not be implemented in other locations as well. By defining the solutions and tasks correctly for other location, several other activities could be improved, such as scheduling and resource allocation. Since, after problems concerning routes of building service systems (which was the original problem of research) are somehow handled, next issues, and maybe even more substantial ones, seems to concern planning of task schedules, pacing of work and task level directions.

As the testing and analyzing phase of research is completed, it is time to move to the final phase – conclusions (Figure 34). In final chapter, the whole research is analyzed and discussed.

Figure 34 Structure and progression of the research

8 Conclusions

Purpose of this research was to generate appropriate solution to tangible problem manifesting as poor productivity of pipe renovation workers on renovation site. Main problem seemed to lie in challenging production environment, that complicated building service system installation works by varying demands and features of building and apartments. As problems concerning renovation works were faced at site, the issue typically either interrupted or delayed the operating. Therefore, intention was to gather and compile effective operation solutions to tackle these common and frequently emerging issues on pipe renovation site to enhance certain project´s problem solving capability by sharing these workable solutions on wider implementation.

Pipe renovation site is indeed dynamic production environment that involves a lot of variability in processes. Thus, to facilitate the situation, decreasing and controlling variability in processes seemed to be relevant measure to improve performance at site and in this manner, increase productivity in pipe renovation project.

Constructed model comprises operation solutions with required tasks for common needs of customer in pipe renovation project. Operation solutions covers basically needs concerning apartments other locations/rooms than bathroom. Solutions demonstrates how certain operation is completed and which tasks this operation solution requires. In this manner, forthcoming operations could be determined beforehand (before renovation phase), or, if unexpected issue occur during operating, workable solution may be found from standardized operation solution model in short order. These manners should decrease site management´s need for operation planning during renovation phase as well as ease the problem solving.

As results shows, selecting of appropriate standardized operation solution for certain element and location succeeded quite well and unexpected issues concerning routing and installation works were also mainly avoided. So, positive signals for that part was perceived. However, research revealed other significant issues interfering production of pipe renovation project.

Construction of new solution/model provided alternative way to observe the production in pipe renovation site. In this research, new constructed model permitted three separate aspect:

1. Direct solutions for different issues concerning routing and installation works of building service systems in apartment level.
2. Control of variability by determining what are the implemented manners to overcome obstacles.
3. Model provided nomenclature, concepts and structure for production by determining the standardized operation solutions with involved tasks.

Although, the aspect 1 might provide most direct and tangible facilitation for pipe renovation production by providing solutions for operation planning, the most significant contribution of model in broader perspective could be the structuring of model and determination of operation solutions and tasks. As the operation solutions are rather location and situation specifics, the model and its structure itself is more generic. The model could be developed further as well as adapt it to other locations as discussed earlier. The major issues hindering the efficient production in pipe renovation seems to be result of unsystematic production controlling and high level of undefined operating.

8.1 The objectives of the research and achievement of them

As objectives of this research could be divided in two categories – first, find solution for prevailing issue and second, acquire broader comprehension of the topic, the research could consider to be succeed moderately. Research questions concerning operational characteristics of pipe renovation and composition of solutions were concluded more explicitly, than question concerning other fundamental issues hindering operational performance at renovation site and utilization of constructed model. Latter ones may require more elaboration. It could be thought that solving one problem disclosed other problems, that were in the shade of the original problem. On the other hand, this insight is a result as well, since more profound understanding of the topic was objective of research, too. So, more open research question was somehow necessary for this research, since the nature of the problem was not that obvious in the very beginning.

What comes to utilization of the solution model, the opportunities are still many. Although, the relevant implementation of the constructed model in test project was based on empirical and theoretical findings, the actual testing in practice provided more holistic perspective for the utilization of the model. This feature could be considered as one evident advantage of constructive research approach. On the other hand, before the use of constructed model could be extended further, the model should be tested to prove its reliability on its very basics. Otherwise the implementation and development of the model would be rather awkward.

Solution oriented approach of research emphasized that, defining the current issue and state of company by objective investigation, is not enough. Research required active participation to project and field study, to gain more empirical comprehension of the topic. Concerning the outcomes of the research, active and observation based approach of topic may provide more realistic, but implicit appearance. Theoretical observation alone may create slightly ideal picture of topic. Certain issues (routing and installation) were somehow facilitated, but as the complex nature of construction production insist, more remarkable productivity improvements may ensue from sum of several factors.

8.2 Critical evaluation of results and potential errors of research

First, as earlier mentioned, complex production in dynamic environment may not be easiest object to measure. Since operating and actions on site were more or less undetermined, one significant task was to determine something, in order to measure it. In this research, the determined features were standardized solution with involved task and categories for emerged problems on sites. Therefore, results gained from research may remain somehow open for interpretation. Sampling for research could also considered to be relatively narrow for further conclusions. However, regarding the size and schedule of the research, these results may although be approximate. It should be noted that conclusions, drawn from the results, might vary depending on the interpreter. But on the other hand, phenomena in construction production would not always be that obvious, as it first seems, as this research also indicates. As complex system is under observation, hasty conclusions may lead to astray.

It should be noticed, that the constructed the model is nothing but alternative frame of reference to comprehend pipe renovation production. Question is not to prove that this model is only true way to improve productivity in pipe renovation projects. Anyway, significant advantage of the model that could be mentioned, is the construction process of the model, that utilized relevantly theoretical and practical aspects.

For abovementioned reasons, this research should be viewed with sound criticism. However, concerning the objective of the research, the essential things are the positive signals – the constructed model somehow works in practice and seems to be quite reliable.

8.3 Potentials for future research

In a way, this research opened the game concerning the utilization of standardized solution model in pipe renovation context. Potential future aspects are many. Model could be developed further, for example towards task descriptions. The structure of model could be utilized in other locations or other fields of construction such as conventional renovation and new construction. Therefore, utility of the model could be tested in other locations, or fields as well. Other possibilities would be the transfer of model in digital platforms. Thus, features concerning communication could be observed and improved more profoundly.

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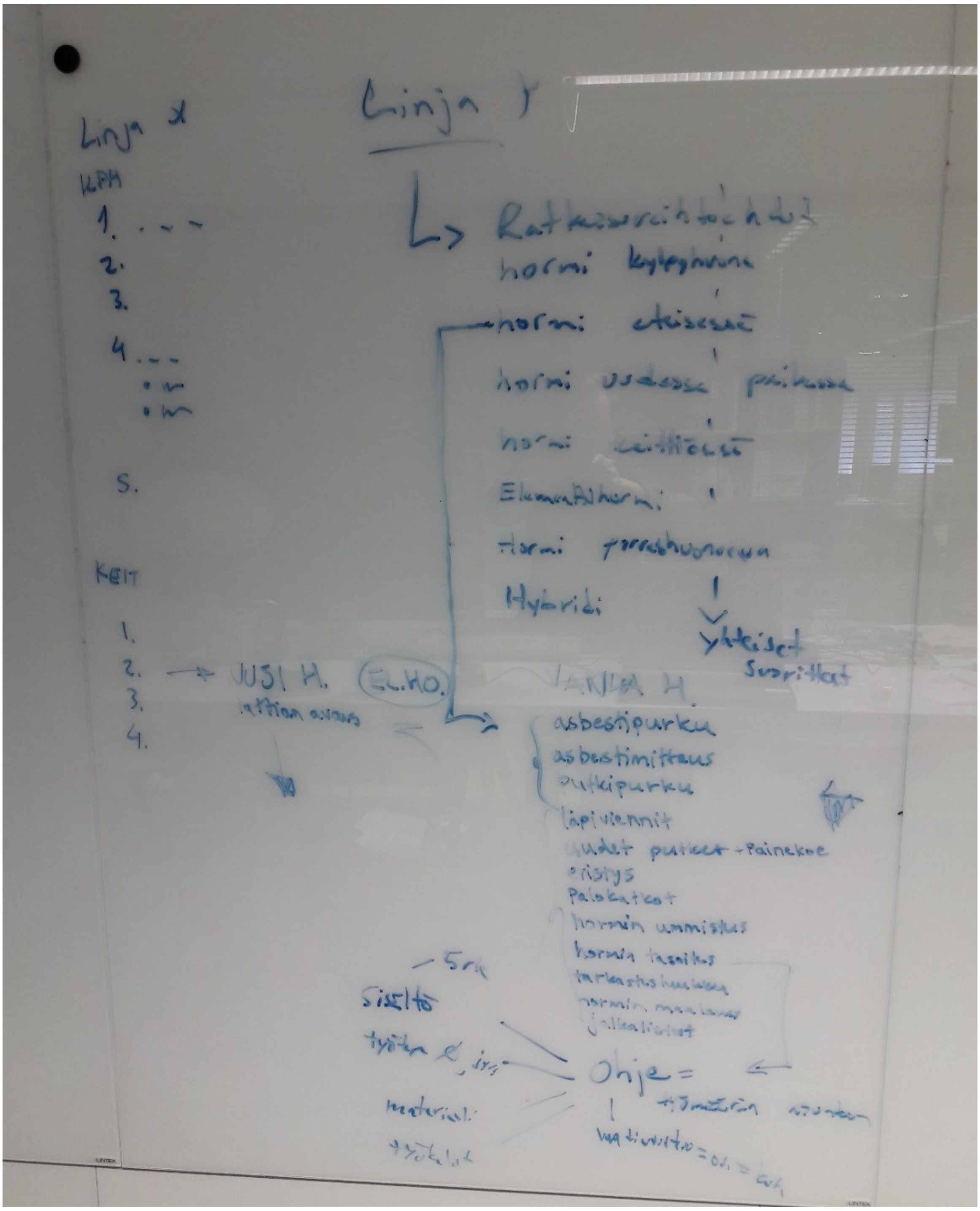
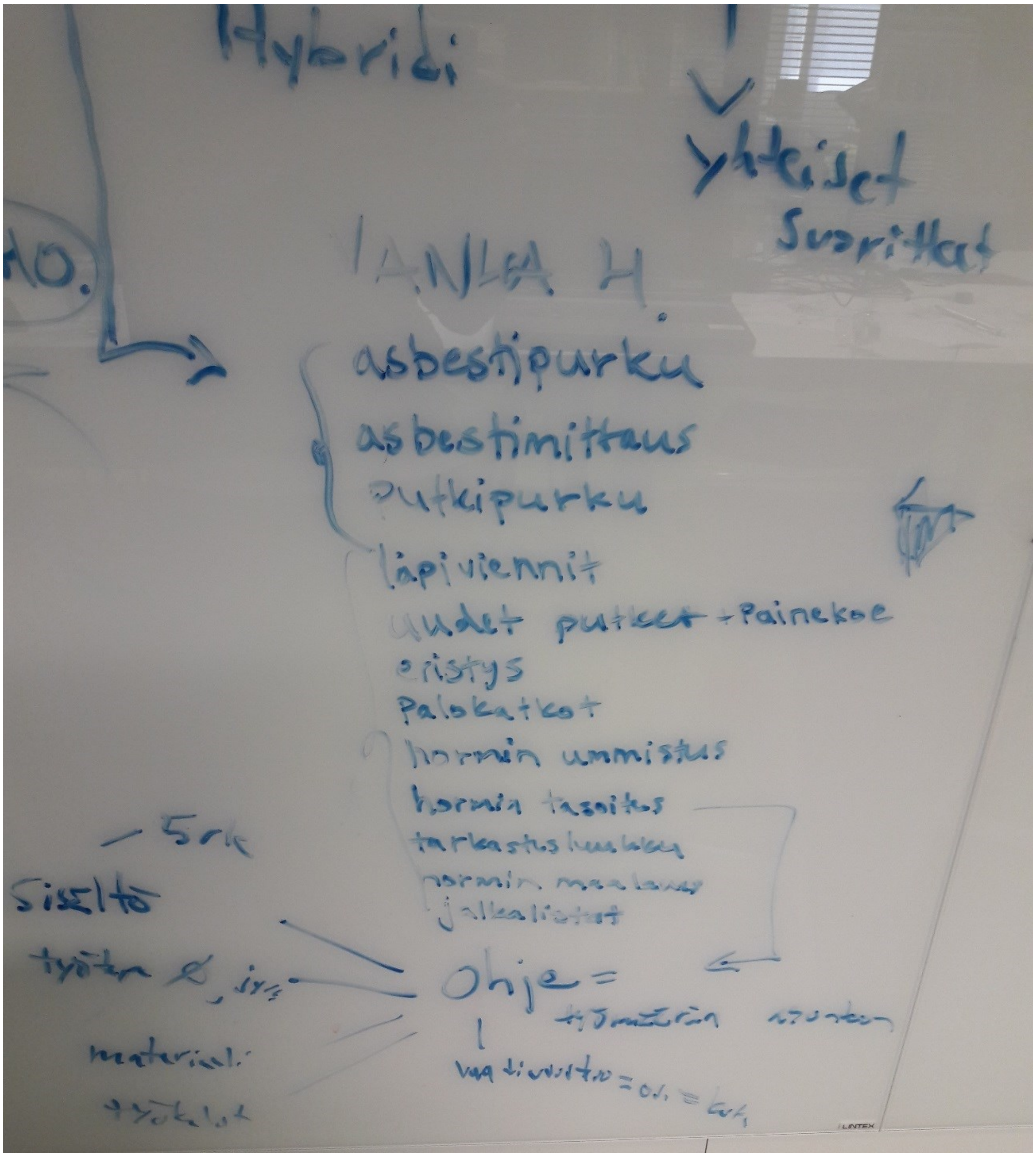
Appendices

Appendix 1. Initial sketches of constructed model. 5 pages.
Appendix 2. Determined standardized solutions and illustrative photos. 8 pages.
Appendix 3. Standardized solutions and involved tasks utilized in test project. 3 pages.

Appendix 1: Initial sketches of constructed model

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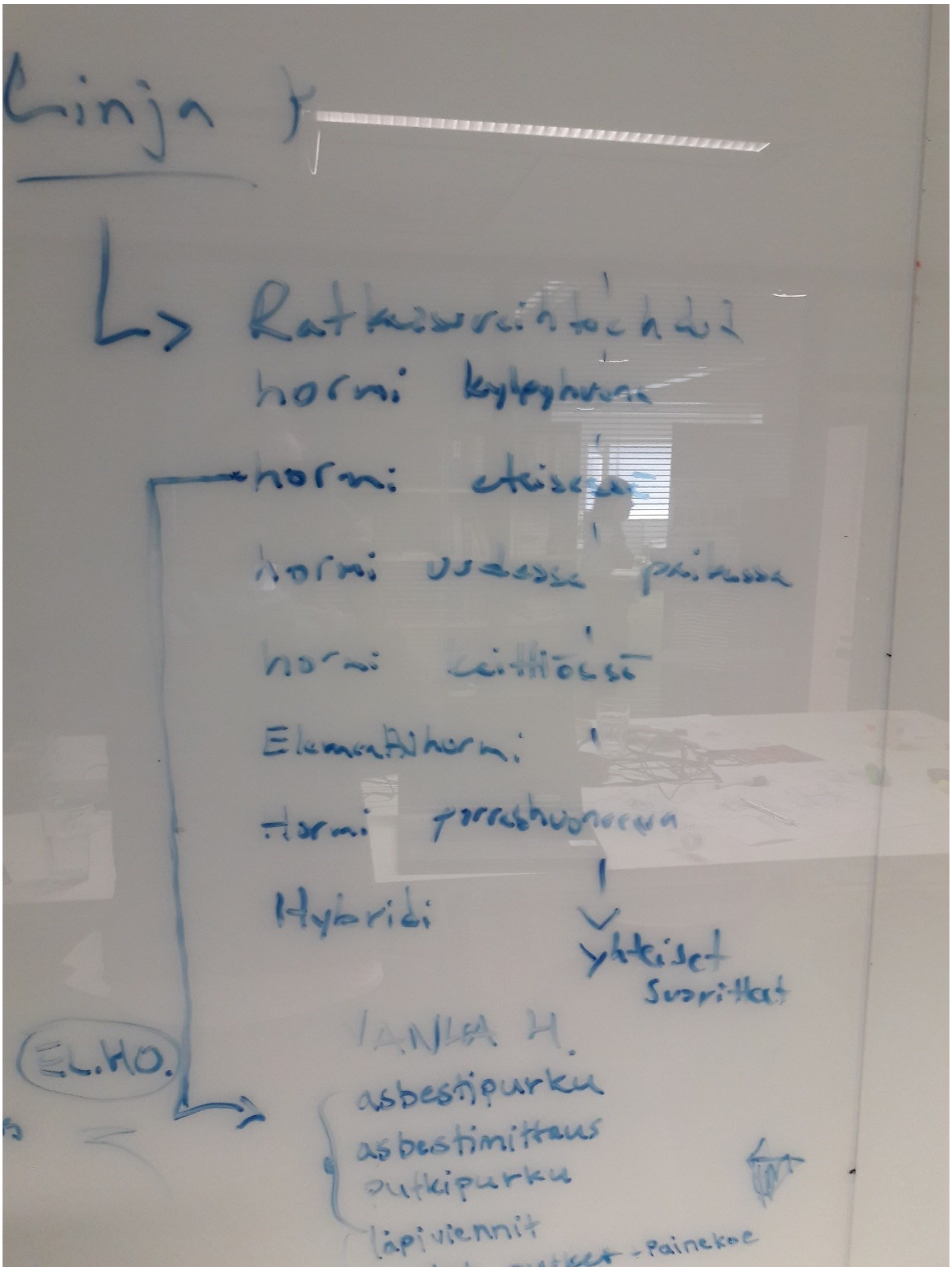
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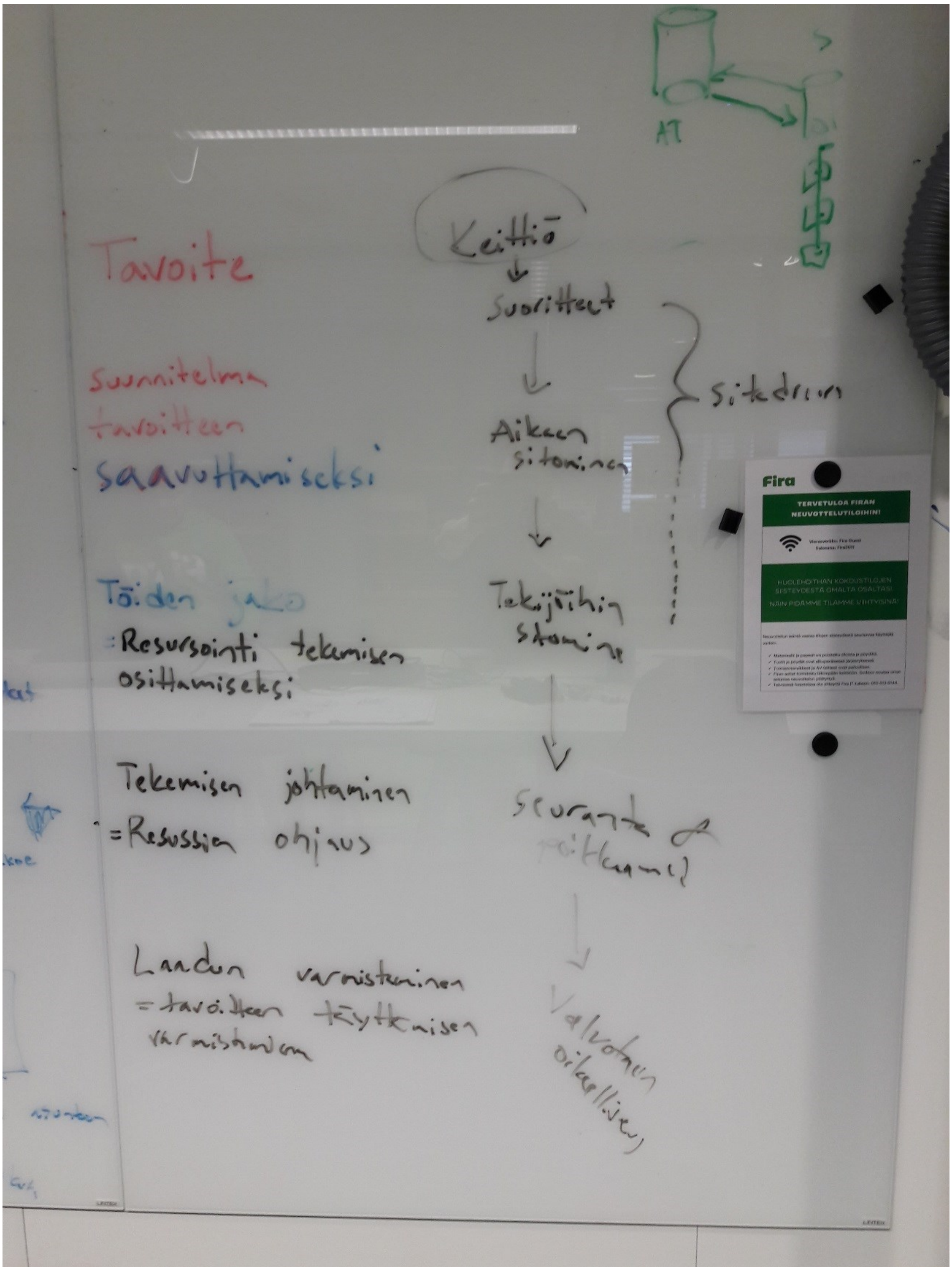
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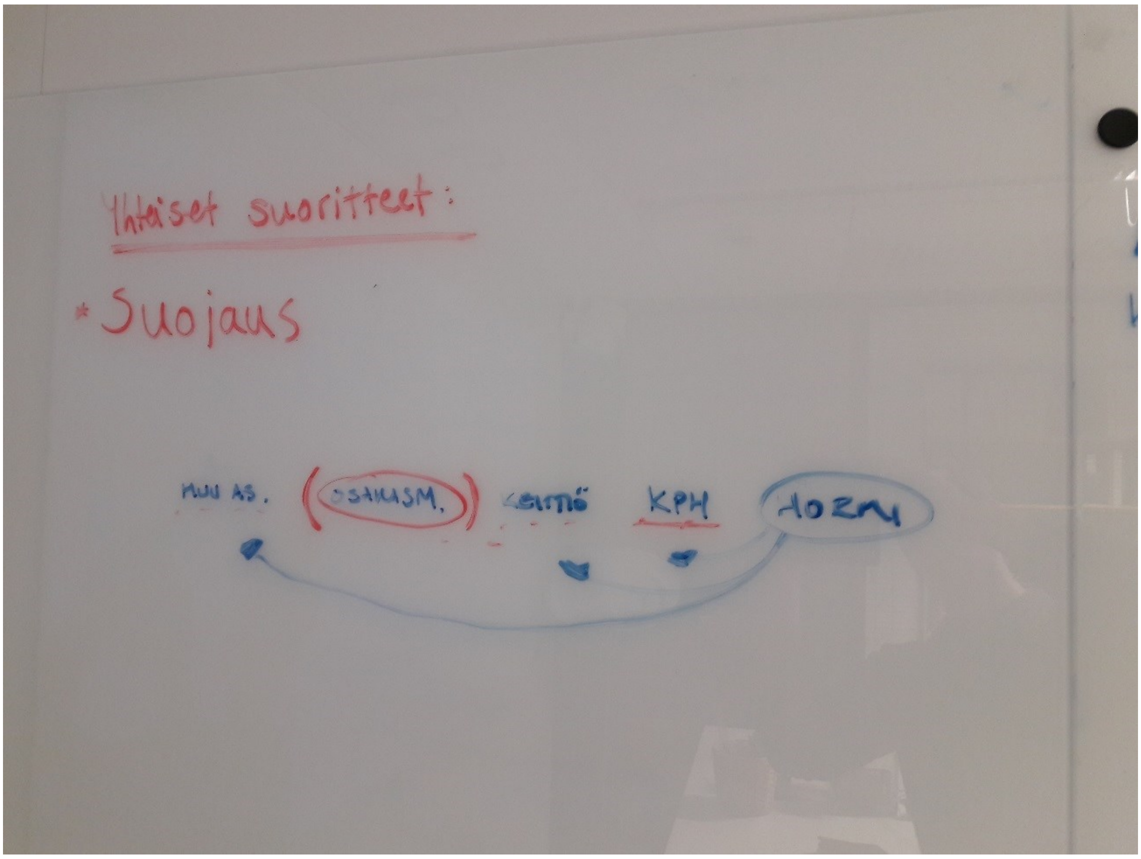
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Value of information increases
To make reasonable decisions we need either requisite information or luck
Building
Project
Process
Solution/ New construction
Tasks
Border conditions
Hungry for relevant information; base of decisions
Portfolio flow I
Project
Building
Clients demands/ Value
Plans?
Structural requirements & regulations
Process/ location
Room/ location flow II
Solutions
New construction (compilation of tasks)
Tasks/operations
Trade flow III
materials
Tools

Appendix 2: Determined standardized solutions and illustrative photos

	Sewer
No.	Solution
1	Existing duct (staircase)
2	New duct (staircase)
3	Existing duct (apartment)
4	New duct (apartment)
5	Branch from vertical line
6	Diagonal diamond drilling into a ceiling of lower apartment´s bathroom
7	Sewer branching in ceiling of lower room
8	Sewer branching in floor casting
9	Sewer branching at basement level
10	Sewer pipe at lower plinth of cabinet
11	Horizontal route of sewer pipe drilled in floor
12	Sewer pipe at casing structure
13	Connection to existing ventilation sewer
14	New ventilation sewer

	Ventilation
No.	Solution
1	Renewing of exhaust valve
2	Shifting of exhaust valve
3	Extension of ventilation duct
4	Reorganization of ventilation ducts
5	Exhaust valve to upper plinth
6	Exhaust valve to ceiling
7	Exhaust valve attached to modified cabinet door

	Water
No.	Solution
1	Existing duct (staircase)
2	New duct (staircase)
3	Existing duct (apartment)
4	New duct (apartment)
5	Branch from vertical line
6	Diagonal diamond drilling into a ceiling of lower apartment´s bathroom
7	Branch from bathroom ceiling
8	Water pipes in floor casting of bathroom
9	Water pipes at lower plinth of cabinet
10	Horizontal route of water pipes drilled in floor
11	Water pipes at ceiling boundary in casing structure
12	Lifting of water pipes at casing structure
13	Lifting of water pipes at duct
14	Lifting of water pipes behind cabinet
15	Vertical route of water pipe drilled in wall
16	Water pipe branching at basement level
17	Branching of water pipes in ceiling
18	Branching of water pipes on wall
19	Higher utilization of one vertical water line than originally planned

	Electricity & Data
No.	Solution
1	Shifting of switchboard
2	Electric wires at ceiling boundary in plastic casing
3	Electric wires at ceiling boundary in casing structure
4	Electric wires at new ceiling
5	Electric wires at existing ceiling
6	Electric wires at bath room ceiling
7	Horizontal route of electric wires drilled in floor
8	Electric wires at upper plinth of cabinet
9	Electric wires inside cabinet
10	Electric wires in floor casting of bathroom
11	Electric wires at lower plinth of cabinet
12	Lifting of electric wires behind cabinet
13	Lifting of electric wires in plastic casing
14	Lifting route of wires drilled on bath room wall
15	Lifting of electric wires at duct
16	Lifting of electric wires behind cabinet
17	Lifting of electric wires inside cabinet
18	Utilization of existing routes

Figure 35 Existing duct & Sewer pipe at lower plinth of cabinet & Water pipes at lower plinth of cabinet

Figure 36 Horizontal route of water pipes drilled in floor & Horizontal route of electric wires drilled in floor

Figure 37 Water pipes at ceiling boundary in casing structure & Electric wires at ceiling boundary in casing structure & Shifting of exhaust valve

Figure 38 Horizontal route of sewer pipe drilled in floor & Horizontal route of water pipes drilled in floor & Horizontal route of electric wires drilled in floor

Figure 39 Sewer branching in floor casting

Figure 40 Diagonal diamond drilling into a ceiling of lower apartment´s bathroom & Diagonal diamond drilling into a ceiling of lower apartment´s bathroom

Figure 41 Sewer branching at basement level & Sewer pipe at lower plinth of cabinet & Water pipe branching at basement level & Water pipes at lower plinth of cabinet

Appendix 3: Standardized solutions and involved tasks utilized in test project

Element	Solution	Task
Sewer		
1	Branch from vertical line	
		Removing kitchen cabinets & appliances
		Diamond drilling (horizontal)
		Sewer routing
		Fire stopping
		Fill casting
2	Sewer pipe at lower plinth of cabinet	
		Sewer routing
		Sewer connection
		Fitting of kitchen cabinets
		Water sealing of cabinets (leak detection)
3	Sewer branching at basement level (Toilet)	
		Demolition of floor tiling
		Diamond drilling (vertical)
		Sewer routing
		Fire stopping
		Fill casting
3	Sewer branching at basement level (Kitchen)	
		Removing kitchen cabinets & appliances
		Diamond drilling (vertical)
		Sewer routing
		Fire stopping
		Fill casting
		Fitting of kitchen cabinets
		Sewer connection
		Water sealing of cabinets (leak detection)
4	Sewer branching in ceiling of lower room	
		Diamond drilling (vertical)
		Sewer routing
		Fire stopping
		Fill casting
5	Diagonal diamond drilling into a ceiling of lower apartment´s bathroom	
		Diamond drilling (diagonal)
		Sewer routing
		Fire stopping
		Fill casting
6	Existing duct	
		Removing kitchen cabinets & appliances
		Opening of duct
		Demolition of old sewer line
		Installation of new vertical sewer line
		Connection to existing ventilation sewer
		Fire stopping
		Fill casting
		Masonry

Element	Solution	Task
Water		
1	**New duct**	
		Demolition of floor tiling
		Diamond drilling (vertical)
		Installation of new vertical water pipe line
		Water meters and stopcocks
		Insulation of pipes
		Fire stopping
		Caising structure
2	**Branch from vertical line**	
		Drilling perforation for water pipes
		Routing of water pipes
		Masonry
3	**Water pipes at lower plinth of cabinet**	
		Routing of water pipes
		Water connection
4	**Water pipes in floor casting of bathroom**	
		Drilling perforation for water pipes
		Routing of water pipes
5	**Lifting of water pipes at casing structure**	
		Routing of water pipes
6	**Branching of water pipes on wall**	
		Surface installation of water pipes
		Water connection
7	**Branching of water pipes in ceiling**	
		Water meters and stopcocks
		Surface installation of water pipes
		Branching of water pipes
		Water connection
		Ceiling works
8	**Water pipe branching at basement level**	
		Diamond drilling (vertical)
		Routing of water pipes
		Fire stopping
		Water meters and stopcocks
		Water connection

Element	Solution	Task
Electricity & Data		
1	Shifting of switchboard	
		Shifting of switchboard
2	Electric wires at ceiling boundary in plastic casing	
		Installation of plastic casing
		Routing of electric wires
3	Electric wires at floor limit in plastic casing	
		Installation of plastic casing
		Routing of electric wires
4	Electric wires at upper plinth of cabinet	
		Removing plinth plate
		Routing of electric wires
5	Electric wires through wall	
		Drilling perforation for electric wires
		Routing of electric wires
6	Electric wires in bathroom ceiling	
		Routing of electric wires
7	Electric wires at lower plinth of cabinet	
		Routing of electric wires
8	Lifting of electricity wires behind cabinet	
		Modification of cabonet
		Routing of electric wires
9	Lifting of electricity wires in plastic casing	
		Installation of plastic casing
		Routing of electric wires
10	Lifting route of wires drilled on bath room wall	
		Drilling of wall
		Routing of electric wires

Element	Solution	Task
Ventilation		
1	Reorganization of ventilation ducts	
		Demolition of old ventilation duct
		Masonry
		Diamond drilling (vertical)
		Routing of ventilation duct
		Installation of exhaust valve
2	Renewing of exhaust valve	
		Installation of exhaust valve
3	Valve attached to modified cabinet door	
		Modification of cabinet
		Installation of exhaust valve